Using Industry Data to Make an Impact on Construction Practices over the Project Lifecycle

by

Namho Cho

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Graduate Supervisory Committee:

Mounir El Asmar, Chair
George Edward Gibson, Jr.
Kamil E. Kaloush

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ABSTRACT

The construction industry generates tremendous amounts of data every day. Data can inform practitioners to increase their project performance as well as the quality of the resulting built environment. The data gathered from each stage has unique characteristics, and processing them to the appropriate information is critical. However, it is often difficult to measure the impact of the research across project phases (i.e., planning, design, construction, operation and maintenance, and end-of-life). The goal of this dissertation is to present how industry data can be used to make an impact on construction practices and test a suite of methods to measure the impact of construction research across project phases. The dissertation provides examples of impactful research studies for each project phase to demonstrate the collection and utilization of data generated from each stage and to assess the potential tangible impact on construction industry practices. The completed studies presented both quantitative and qualitative analyses. The first study focuses on the planning phase and provides a practice to improve frond end planning (FEP) implementation by developing the project definition rating index (PDRI) maturity and accuracy total rating system (MATRS). The second study uses earned value management system (EVMS) information from the design and construction phases to support reliable project control and management. The dissertation then provides a third study, this time focusing on the operations phase and comparing the impact of project delivery methods using the international roughness index (IRI). Lastly, the end-of-life or decommissioning phase is tackled through a study that gauges the monetary impact of the circular economy concept applied to reuse construction and demolition (C&D) waste. This dissertation measures the

impact of the research according to the knowledge mobilization (KMb) theory, which illustrates the value of the work to the public and to practitioners.

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1. INTRODUCTION

1.1 Background and Objective

Technological developments can change industries significantly. In the construction industry, there are changes at all phases of construction projects, including planning, design, construction, operation and maintenance (O&M), and end of life (EOL). For example, one of the novel developments is building information modeling (BIM), which allows multi-dimensional modeling of facilities where design, structural tests, planning, and project control may be performed in one platform (Ding et al. 2014). Moreover, project owners can use some of this generated data for the maintenance of their project so that they can set up comprehensive planning for their facility management once the project has been completed (Love et al. 2014). Akhavian and Behzadan (2012) state that the dynamic nature and complexity of most construction operations lead to a significant need for a methodology that combines the capabilities of traditional modeling of engineering systems and real-time data collection from the field.

Technological developments not only affect construction, but also the use of these built facilities. Smart cities use the internet of things (IoT) to collect information from the facilities and provide optimized solutions for residents and governments that are able to monitor the overall status of their city (Masek et al. 2016). One example is the Seoul city government in South Korea, where the mayor and city council can access infrastructure information in real-time of a natural disaster, including safety and traffic conditions of the city, which helps inform their decision making (Kang 2019).

Such new technologies are starting to change the current construction industry significantly. Real-time monitoring systems generate tremendous amounts of data. However, in many instances it is still difficult to make full use of the data due to the lack of data integrity (Akhavian and Behzadan 2012). For example, construction data should ideally be available all the way through the O&M stage, and then O&M data from existing facilities should ideally be transferred to the planning process of new projects to make better-informed decisions for new construction projects. Such large datasets require improved data collection, treatment, and analysis to make an impact on the various phases of construction projects.

In addition, processing data from each stage to appropriate information is critical. Data are symbols that represent the properties of objects and events, and information consists of processed data, the processing directed at increasing its usefulness (Ackoff, 1989). Winch (2010) analyzed construction information processing and determined characteristics based on four construction lifecycle stages: (1) data in the briefing stage is iterative, divergent, and ill-structured; (2) data in the design stage is still iterative around an ill-structured, but more convergent; (3) data in planning is more reciprocal than iterative and well structured; and (4) data in the execution stage is well structured, and information processing in this stage tends more toward either sequential or pooled, as well as reciprocal information flows that still remain in high uncertainty aspects. Since different stages have unique characteristics, the appropriate strategy to building effective and efficient information is critical in the construction industry.

Even though researchers recognize multiple forms of research influence, it is challenging to identify when, how, and to what extent the research impacts the industry and general public (Dobbins et al. 2007; Tseng 2012). Levin (2013) discussed a significant reason for this issue because of the serious difficulties of differing ideas about what should count as 'research' and what should count as 'use' or application. This discussion mainly focused on social science research projects, but construction-related research also needs to consider this issue because of construction's significant impact to the public (e.g., buildings, roadways, dams, bridges, etc.)

A conceptualization of the knowledge mobilization (KMb) process identifies three overlapping and interacting domains – the production of research, the end-use of research, and the intermediary processes that link these two (Levin 2013). The term KMb is developed from knowledge management (KM) to show a set of concepts and practices that optimizes access and use of knowledge. KM addresses the supply side of information, the creation of environments for communication and collaboration, leveraging intellectual capital, and incentives for shifts in work practices (Keen and Tan 2007). Conversely, KMb reflects the demand side that is dominated by knowledge being part of individual identity and hence the personal choice of whether, where, why, and with whom to share knowledge and expertise (Keen 2006; Qureshi and Keen 2005). Therefore, it interactively increases the utilization of the research results from the user side.

To maximize the utilization of research results, the Arizona State University Graduate College (2019) provides best practices for KMb. The best practice offers six steps to maximize their impact across multiple audiences and contribute to the public good: (1) identify the problem/challenge/issue, (2) explain the solution, (3) discuss how the work is made accessible to others, (4) discuss how the use of the work is being promoted, (5) show evidence of the work's impact, and (6) provide a call to action. The process steps (4) to (6) can be seen as improvements to conventional academic research by promoting accessibility and demonstrating the impact of the research work.

This dissertation addresses the gap between using industry data for construction research, and the resulting impact on construction practice, throughout the construction business and project lifecycle. First, this research determines the construction business and project lifecycle and examples of available data in each stage. Then, each research project presented is an example of impactful work within one of the listed project stages, to show the use of the data and its impact on construction practice. The structure of each chapter follows the best practice of KMb to illustrate the "impact" of the study.

1.2 Problem Statement

Due to the long life span of built facilities and the impacts from, and on, diverse stakeholders, the construction process can generate numerous and complex data sets. Moreover, technology improvements contribute to increasing the size and complexity of said data. In order for the generated data to reach its full potential in informing decisions, data needs to be timely, mature, reliable, integrated, and usable at various points during the construction lifecycle.

Data generated from each project stage are different and relatively unique, with their own information processing issues. For example, information processing in the early planning stage is both iterative and divergent, looking outward in broad search for solutions to solve an oftentimes ill-structured problem. In comparison, information processing in the construction stage is usually better structured because the "problem" is more defined at this stage, but reciprocal information flows govern uncertainty on site (Winch 2010). Therefore, the appropriate use of the data generated from the construction lifecycle is vital for project success.

Once data is used in the research, the impact of the research should be measured, particularly when it comes to using the research results to improve practice. However, oftentimes research projects do not gauge the financial and practical impact of the work; and therefore, some outstanding research studies are ignored by the industry and public (Dobbins et al. 2007; Levin 2013; Tseng 2012).

The goals of this study are (1) providing an example of an impactful research study for each of the construction project lifecycle stages to illustrate the utilization of data generated from each stage, and (2) assessing the potential impact of construction data and research on construction practices. This study includes examples of both quantitative and qualitative data analyses that can be implemented throughout the project lifecycle, resulting in benefits to both research institutions and industry practitioners by informing construction project decision-making.

1.3 Research Objective and Scope

The research objectives of this dissertation are to:

1. Assess the potential impact of construction data and research on construction practices. Gauging the financial and practical impact of research helps increase the use and accessibility of the work.
2. Provide an example of an impactful research study for each project lifecycle stage: planning, design, construction, operation and maintenance, and end of life.

The scope of this research covers the entire construction project lifecycle, as shown in Figure 1.1. A construction project lifecycle can organized in five phases (El Asmar et al. 2020; Carra and Magdani 2017; Gibson et al. 1995; Graham 2018). The bar chart in the figure represents the phases where each study applies.

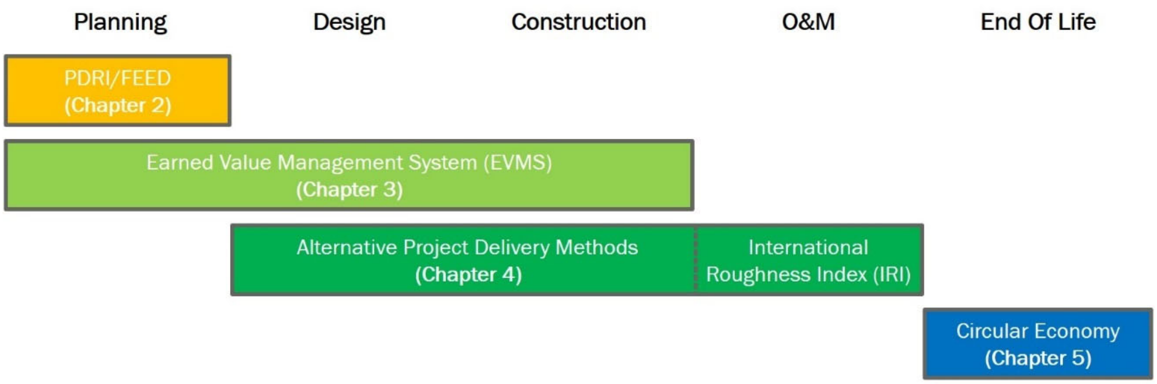

Figure 1.1 Research Scope of Each Chapter on the Construction Project Lifecycle

The applications of this research presented in this dissertation cover diverse types of facilities. Chapter 2 discusses the project definition rating index (PDRI) development and implementation during the front end planning (FEP) stage. The chapter applies to various types of industrial construction projects, including chemical, gas, factory, mining, and ship production. Chapter 3 targets practices and reviews of earned value management system (EVMS) implementation and execution, applied to government capital projects, defense projects, energy projects, and manufacturing. Chapter 4 illustrates the use of O&M performance data to measure the impact of alternative project delivery methods (APDM) on pavements. The U.S. national highway system (NHS) is the main application of the chapter, where potential audiences are various state Departments of Transportation (DOT) and other highway agencies. Lastly, Chapter 5 illustrates quantifying the monetary benefits of construction and demolition (C&D) debris, through adopting a circular economy (CE) model in the U.S. construction market.

1.4 Research Methodology

This section outlines the overarching research method used in this study. Throughout the lifecycle of the project, different types of data are collected, and each type of data and objectives lead to a different methodology and analysis. Different chapters will use different research methodologies, including quantitative analyses, qualitative analyses, or both. Specific research methods and concepts, including literature reviews, interviews, charrettes, surveys, statistical analysis, time series analysis, and economic analysis procedures are described. Moreover, each chapter includes the estimated impact of the work based on the KMb concept (Arizona State University Graduate College 2019; BenMoussa 2010; Keen 2006; Levin 2013). Table 1.1 provides highlights of the research methods and data analysis techniques used throughout this study. A more detailed methodology discussion is presented as part of each chapter.

Table 1.1 Research and Data Analysis Methods

Chapter Number	Project Phase	Research Method	Data Analysis
Chapter 2	Planning	Literature Review; Statistical Analysis; Charrette; Embedded Multi-Case Study	One-way ANOVA Test; Independent Sample t-test
Chapter 3	Planning, Design, and Construction	Literature Review; Survey; Charrette	Word Frequency Analysis
Chapter 4	Design, Construction, and O&M	Literature Review; Statistical Analysis; Time Series Analysis Nested Modeling; Life cycle cost analysis	Linear Mixed-Effects Model
Chapter 5	EOL	Literature Review; Economic Analysis; Interviews	Economic Simulation

1.4.1 Use of Front End Planning Data

PDRI is a tool that documents and supports the FEP process. Chapter 2 introduces the development of the PDRI version 5, which was completed in 2019 and titled PDRI maturity and accuracy total rating system (PDRI MATRS). The chapter also provides a guide for successful application of the tool. In a follow-up study that builds on the PDRI development, the author focused on some projects with superior PDRI maturity scores, but where the project experienced cost overrun and/or schedule delay. To investigate these projects further, the author used a multiple case study methodology as shown in Taylor et al. (2011) and Yin (2018). Longitudinal data were collected, building on a research charrette performed with 32 industry experts, which and helped identify the significant FEP attributes affecting project delay and cost overrun. The last step of this study investigates the impact of PDRI MATRS scores on project performance.

1.4.2 Use of Project Control Data

Chapter 3 describes the current state of knowledge and challenges of implementing EVMS on large complex projects. The study reviews the rich EVMS literature and provides a timeline analysis of literature for the past couple of decades. In addition to the literature review, this study included developing an industry survey to gauge the current state of practice from EVMS experts. The contributions of the work included five major topics: (1) standard definition of earned value management (EVM)/EVMS, (2) current practices of EVMS maturity assessment, (3) EVMS application challenges, (4) EVMS implementation and execution processes, and (5) EVMS environment. The survey results were analyzed by keyword frequency and rank orders.

1.4.3 Use of Pavement Performance Data

During the O&M stage, tremendous amounts of data is collected to monitor the status of built facilities. The objective of Chapter 4 is to assess the impact of the design-build (DB) project delivery method on the long-term performance of pavements. First, based on a detailed literature review, international roughness index (IRI) was adopted as the performance metric for the study. The data was collected with very stringent requirements to ensure valid comparisons between design-bid-build (DBB) and DB projects. In addition, data consistency was evaluated based on individual project information. Then, linear mixed-effects (LME) models were developed based on the modeling protocols presented in Pinheiro and Bates (2000) and Zuur et al. (2009). The parameters that correspond to fixed effects were evaluated and supported achieving the research objective. The last step of this research estimated the financial impacts of the findings.

1.4.4 Use of End of Life Data

The appropriate use of EOL data supports sustainable construction. Chapter 5 provides a framework to estimate the monetary benefits of applying CE in the construction industry. The objective is to highlight the opportunities available to allow the built environment stakeholders to identify where the leverage points are, along with the financial opportunities associated with changing current business models to circular ones. The chapter identifies three key stakeholders participating in C&D debris recycling: waste generators, recyclers, and end-users. Each stakeholder's interests are different and may conflict with one another, so it is essential to estimate their benefits separately. This study applies macro-scale data published by the country of South Korea and by the U.S. Environmental Protection Agency (EPA), and estimates the potential market value of C&D waste based on an economic analysis.

1.5 Dissertation Structure

The next four chapters of this dissertation are organized into a complete academic journal paper format. Chapters 2, 3, 4, and 5 each represent an independent, stand-alone article and, therefore, include their own abstract, introduction, review of the relevant literature, methodology, analysis, discussion of results, conclusion, the impact of the research, and references specific to the content of that article. Figure 1.2 shows an overview of the dissertation structure and is meant to be read from the bottom up.

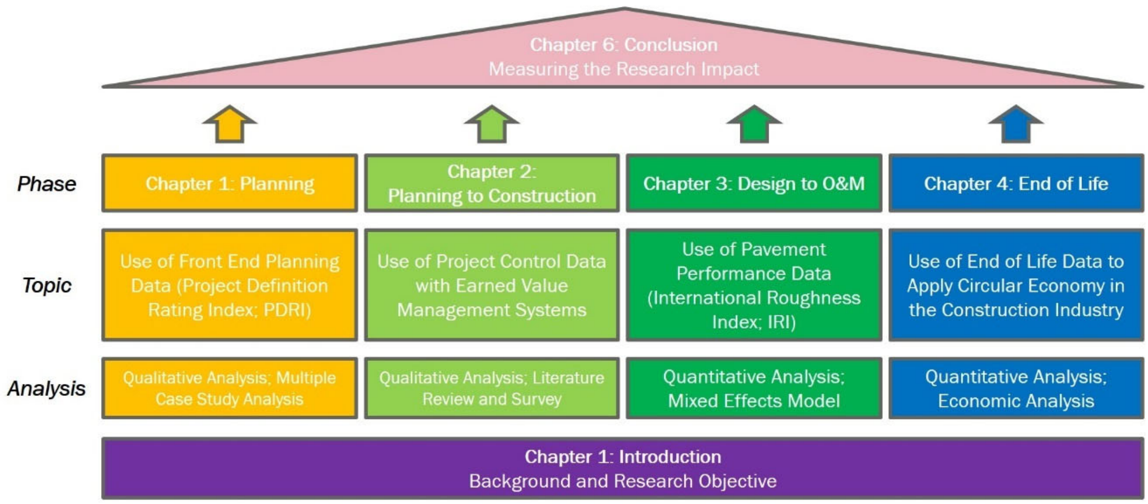

Figure 1.2 Dissertation Structure

This chapter, Chapter 1, introduced the theme of the research, problem statement, research objectives, project scope, overarching research methodology, and the structure of the dissertation.

Next, Chapter 2 presents how FEP data can be used to improve project cost and schedule performance. The chapter documents the development of the PDRI MATRS tool that supports the FEP process, and analyzes current assessment practices that can improve the use of the tool. My contributions in Chapter 2 are analyzing PDRI score data and reporting, and Construction Industry Institute (CII) research team (RT) 331 and 361 greatly supported finalizing the research project. A portion of this chapter is published as a CII implementation resource (IR), and part of the chapter is being prepared as a journal article, expected to be submitted to “Engineering, Construction and Architectural Management,” published by Emerald Publishing as well.

Chapter 3 illustrates the use of project control data to improve the reliability of EVMS by analyzing literature and current practice. The chapter provides the basis for developing an EVMS METR tool, providing a foundation from the literature review and survey analysis. My contributions to Chapter 3 are literature review and survey development, and EVMS METR research team has been greatly supportive of the research project. The initial version of this chapter was published as part of the American Society of Civil Engineers (ASCE) Construction Research Congress (CRC 2020) proceedings, and part of this chapter is accepted to the ASCE Journal of Management in Engineering as part of a CRC 2020 special issue.

Chapter 4 analyzes pavement performance data to test the impact of APDM on long-term performance. This chapter illustrates the application of engineering data to support decision-making and project management. This chapter is derived from an article published in the Korean Society of Civil Engineers (KSCE) Journal of Civil Engineering.

Chapter 5 discusses the use of EOL data to find potential monetary value to support CE adoption in the U.S. construction industry. An early version of this chapter is published as a Master student thesis and ranked as a finalist at the 2018 Korea Environment Institute (KEI) international paper competition. It is now being prepared as a journal article and expected to be submitted to Journal of Business Research, Elsevier, special issue titled "Circular Economy in Small and Medium Sized Enterprises – Theoretical Developments, Practical Challenges and Future Research Agenda."

The final chapter of this dissertation (Chapter 6) presents overall conclusions, major findings of each chapter, and recommendations for future work.

2. USE OF FRONT END PLANNING DATA: QUALITATIVE ANALYSIS

2.1 Abstract

The purpose of this study is updating the project definition rating index (PDRI) by proposing the maturity and accuracy total rating system (MATRS), which was first introduced in front end engineering design (FEED) MATRS study. This tool builds on the original PDRI – industrial and is developed to provide a more consistent mechanism to evaluate the level of definition of engineering design and other scope definition deliverables. It also provides a new evaluation method to assess the accuracy under which an accurate FEP should be developed. PDRI maturity scores were analyzed to determine the compatibility of the PDRI MATRS with the traditional PDRI tool. This study contributes to the existing body of knowledge by providing maturity elements and accuracy factors that can support appropriate construction management, considering both the project itself and its work environment.

2.2 Introduction

A project owner's expectation is to be able to make reliable, sound, and informed project decisions based upon front end planning (FEP) and front end engineering design (FEED) development, including cost and schedule predictions, that can lead to deciding whether or not a project should move forward to detailed design, and ultimately leads to better project performance (Gibson et al. 1993). Project teams and owners expend substantial effort to develop the scope definition during FEP of large industrial projects (Gibson et al. 1995). However, these projects many times have either immature or inaccurate front end engineering design (FEED). Yussef et al. (2020) defined FEED as "a component of the FEP process performed during detailed scope (Phase 3), consisting of the engineering documents, outputs, and deliverables for the chosen scope of work." The FEP process culminates with the development of the project definition package (also called the FEED package) consisting of a number of documents needed for the phase gate (PG) 3 decision, which is known as "detailed scope."

The FEP process is emphasized by many researchers to improve project management's ability and performance (Gibson et al. 2006). The Construction Industry Institution (CII) developed a tool supporting the FEP process called the PDRI, which provides critical elements considered during the planning stage of a project. The PDRI tool currently has five different applications for various type of construction projects, including industrial, building, infrastructure, small infrastructure, and small industrial projects (CII 2013a; b, 2015, 2016, 2019a; b).

Since 1996, the PDRI for Industrial Projects has been widely adopted by industry over the past two decades and is a powerful and easy-to-use tool that offers a method to measure project scope definition (CII 2019a). It identifies and describes each critical element in a scope definition package and allows a project team to quickly predict factors impacting project risk (Gibson et al. 1993). To improve the assessment of the project and its environment, and incorporate with FEED maturity and accuracy total rating system (MATRS) study, the comprehensive rating tool, called PDRI MATRS, is suggested in this study. PDRI MATRS helps assess both maturity and accuracy of the project definition package and FEED, and correlate their effects to project performance predictability at the end of the detailed scope phase (phase 3) (CII 2019a; Elzomor et al. 2018; Yussef et al. 2018, 2019, 2020).

PDRI maturity is defined as "the degree of completeness of all FEP deliverables (PDRI elements) that make up the project definition package, serving as the basis for the final investment decision at the end of detailed scope (PG 3)." FEED maturity elements are a subset of the elements making up the entire PDRI. FEED maturity is defined as "the degree of completeness of the deliverables to serve as the basis for detailed design at the end of detailed scope (PG 3)" (Yussef et al. 2019). PDRI accuracy is defined as "the degree of confidence in the measured level of maturity of PDRI deliverables to serve as a basis of decision at the end of detailed scope (PG 3)." Thus, maturity and accuracy are both critical for effective FEP to occur. Maturity is how well the deliverables have been completed. The accuracy measurement component of this tool looks at the environment surrounding the development of scope definition of the project where a mature project definition package can be developed. Hence, accuracy is impacted by factors such as experience, time, process, and so forth.

This chapter presents the new approach of the PDRI by proposing the maturity and accuracy total rating system. This tool builds on the original PDRI – industrial and is developed to provide a more consistent mechanism to evaluate the level of definition of engineering design and other scope definition deliverables. It also provides a new evaluation method to assess the environment under which an accurate FEP should be developed.

2.3 Research Methodology

PDRI MATRS update is suggested to improve the general performance and reliability of the PDRI assessment. It is not only improving objectivity and consistency of the tool, but also expanding its assessment to the environment of the project. Figure 2.1 shows the research method to update PDRI to PDRI MATRS. The first step is analyzing FEP process and PDRI implementation at each PG aligned to FEP. Second, the next step is adding objectivity and consistency to the maturity scoring through detailed descriptions of each possible definition level tailored to each of the 70 elements, with examples. This process also includes identification of a FEED subset of 46 engineering elements that are part of the original 70 PDRI elements, to allow a specific focus on engineering design when needed. Third, a new FEP accuracy dimension to evaluate contextual factors for the environment in which FEP is added, based on the recent FEED MATRS tool, which was integrated with and folded into this new PDRI. Fourth, the new additions are valuated with additional research and show increased cost certainty and change performance, even compared to the outcomes of the original PDRI. Lastly, the impact of PDRI MATRS is discussed.

Updating PDRI to PDRI MATRS	
STEP 1	**Front End Planning and PDRI Application** • Literature review about FEP and its practice • Practical use of PDRI at each Phase Gate • Charrette to determine cost and schedule impact items
STEP 2	**PDRI Maturity and Its Structure** • PDRI Maturity category and elements • PDRI Maturity element rating scheme • PDRI Maturity element description development
STEP 3	**PDRI Accuracy and Its Structure** • PDRI Accuracy category and factors • Rating scheme for accuracy assessment • PDRI Accuracy factors description
STEP 4	**Performance of PDRI and PDRI MATRS** • ANOVA test is performed on collected data and its sub-sets • Link the PDRI maturity score to FEED to check the consistency of the tools
STEP 5	**Impact of PDRI MATRS** • Estimated monetary impact of PDRI MATRS

Figure 2.1 Research Method

2.4 Front End Planning and Application of PDRI MATRS

Gibson et al. (2006) defined FEP as the process of developing sufficient strategic information with which owners can address risks and make decisions to commit resources in order to maximize the potential for a successful project. FEP is also known as front end loading, pre-project planning, feasibility analysis, conceptual planning, programming/ schematic design, sanctioning, and early project planning. Figure 2.2 shows the influence and expenditure curves affecting project performance. During the business planning and FEP stages, any changes significantly influence the project, but requires low expenditures, such as cost, schedule, or other logistics to support changes. Therefore, high quality FEP leads to high quality design documents, ultimately, reducing risks associated with the project's execution phase and its related high expenditures.

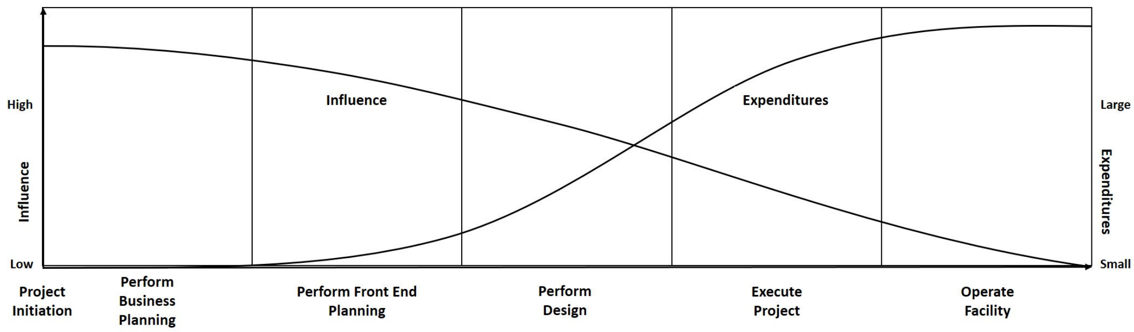

Figure 2.2 Impact of FEP on Project and Expenditures (Adapted from Gibson et al. 1995)

PDRI MATRS is intended to be used during FEP, which encompasses the project activities shown in Figure 2.3 up to PG 3 and includes feasibility, concept, and detailed scope definition. Phase 1 is known as "feasibility," phase 2 is known as "concept," and phase 3 is known as "detailed scope" as seen in Figure 2.3. Each of these phases is followed by a phase-gate that marks a decision to move forward to the next stage of the project. For many projects, FEP is considered to be the most important process within the project lifecycle (e.g., Cho and Gibson 2001; Chokor et al. 2017; Collins et al. 2017b; Dumont et al. 1997; Elzomor et al. 2018; González et al. 2010; Hamilton and Gibson 1996; Hastak and Koo 2017; Javanmardi et al. 2018; Kim et al. 2015b; a; Wu and Issa 2015; Yussef et al. 2018).

PDRI MATRS should be used during the FEP process to ensure alignment, conformance to organizational procedures, and a continual focus on project priorities. The tool can be used both during and at the conclusion of FEP. Specific PDRI MATRS application points are shown in Figure 2.3. Regardless of the timing for the PDRI MATRS assessment, users of PDRI MATRS can utilize the same maturity elements and accuracy factors, and conduct the evaluation according to the guidelines outlined below. Identified FEED elements are recommended to apply at PG 3 only.

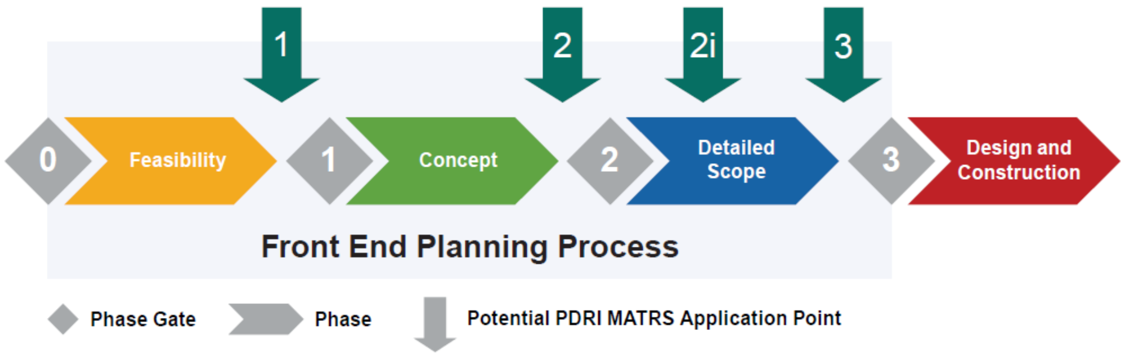

Figure 2.3 FEP Process (CII 2019a)

2.4.1 PDRI 1 Review

This is a high-level assessment of the project following feasibility prior to Phase Gate 1 and is part of the decision criteria for proceeding to the next phase. The PDRI 1 review should focus on the following areas: First, bring an engineering firm on board early in the project, at the initial kickoff meeting. It may have limits to involve an engineering firm during the FEP process based on the project delivery method, but early involvement of engineering inputs should happen in any method (El Asmar et al. 2013; Sullivan et al. 2017). Second, align the team with project objectives. Griffith and Gibson (2001) present 10 critical alignment issues that have the greatest effect on team alignment and ultimate project success. They are currently merged in PDRI Accuracy factors. Alignment should be considered in three dimensions, which represent within-organization, cross-organization, and project lifecycle, and are reviewed during the entire project lifecycle. Third, ensure good communication between the business/sponsor and the project/contractor team. Lastly, highlight stakeholder expectations to facilitate reasonable engineering estimates (AACE International 2005; Bates et al. 2013).

Typical PDRI maturity scores at this assessment will be in the range of 550–800. FEED maturity scores may be much lower than 50 percent; PDRI accuracy scores may be at any point of the 0-100 percent range but would need to be sufficiently high in order to increase the project's probability of success. A low accuracy score at this point would need immediate attention. This assessment should be used to establish baseline values of maturity and accuracy before moving onto the next phase. Using the PDRI accuracy assessment very early enables management to establish the proper environment for successful FEP if it addresses the gaps identified in the session. A PDRI accuracy assessment can be stand-alone at this point.

2.4.2 PDRI 2 Review

This is a high-level assessment following the concept development phase of the project, or PG 2, and is part of the decision criteria for proceeding to the next phase. PDRI Section I, the Basis of Project Decision, should be well-defined (with a low relative PDRI score) at the end of this phase. For small projects, this assessment may not be necessary (Collins et al. 2017; Elzomor et al. 2018). In addition, the PDRI 2 Review should focus on the following areas. First, align project objectives and stakeholders' needs. Second, identify high priority project deliverables that need to be completed. Third, help to eliminate late project surprises. Lastly, facilitate communication across the project team and stakeholders.

Typical PDRI scores at this phase of the project may be in the range of 450–600. FEED maturity scores may be lower than 50 percent; PDRI accuracy scores should be sufficiently high (greater than 76 percent) in order to increase the project's probability of success. A low accuracy score at this point would need immediate attention. The assessment will highlight the areas where resources need to be focused during the next phase of FEP. This assessment also should be used to develop updated values of maturity and accuracy before starting detailed scope.

2.4.3 PDRI 2i Review

This is an intermediate assessment of a project during the detailed scope phase, which typically should be held midway through this phase. Section II, Basis of Design, and Section III, Execution Approach, should be well-defined during this phase of the project. The PDRI 2i Review should focus on the following areas: (1) assure alignment of project objectives and stakeholders' needs; (2) confirm that resources are properly deployed to get the largest value for the time and effort being applied; (3) verify scope in relation to the original project goals; and (4) identify and plan remaining activities to achieve the level of detail necessary to complete front end planning in preparation for PG 3.

Typical PDRI scores at this phase of the project may be in the range of 300–450. FEED maturity scores should be greater than 50 percent; PDRI accuracy scores should be sufficiently high (greater than 76 percent) in order to increase the project's probability of success. A low accuracy score at this point would need immediate attention and should cause concern over the efficacy of FEP effort to date, and the ability to meet project objectives. PDRI 2i review is done in order to assess the evolution of FEP activities and how the FEED is being defined and identify specific issues that may impact accuracy.

2.4.4 PDRI 3 Review

PDRI 3 review is typically the final assessment of the project at the end of front end project planning prior to PG 3. At this stage, risk issues have been identified and mitigation plans are in place or are being developed. Typical scores for this review are 150 to 250, with a target of typically 200 or below. FEED maturity scores should be greater than 80 percent; PDRI accuracy scores should be sufficiently high (greater than 76 percent) in order to increase the project's probability of success. A low maturity or accuracy score at this point would indicate the need for higher contingency and the expectation for additional detail design cost and schedule to resolve difficulties. In fact, research data shows that projects with low maturity or low accuracy scores at this point typically do not meet target cost and schedule. The PDRI 3 assessment should be conducted for all projects to establish final PDRI maturity and accuracy scores for FEP and FEED.

Sometimes project teams are pressured to develop a scope of work in a short period of time. To streamline the process, the team could focus on the top 10 elements listed in Figure 2.4. These 10 elements comprise almost 40 percent of the total score. This is in accordance with the Pareto principle in that a large portion of the effects can be attributed to 20 percent of the causes. When addressing smaller projects, the team may want to select a different "top 10" depending on the circumstances.

1.Products (B1) 2.Capacities (B5) 3.Technology (C1) 4.Processes (C2) 5.Process Flow Sheets (G1) 6.Site Location (F1) 7.P&IDs (G3) 8.Site Characteristics Available vs. Required (D3) 9.Market Strategy (B2) 10.Project Objectives Statement (D1) **TOTAL POINTS = 384/1000**

Figure 2.4 Ten Highest Ranking PDRI Elements

2.4.5 Additional Application of PDRI MATRS

In addition to the four PDRI MATRS reviews outlined above, the tool can be used at other stages in the project. For instance, it can be used early in feasibility as a checklist to help organize work effort or during the design phase (after PG 3) to verify the design before moving on to construction. It has been used effectively as an alignment tool during the kickoff of design-build (DB) or engineer-procure-construct (EPC) projects (Dicks et al. 2017b; Gibson and Gebken 2003a; Ramsey et al. 2016).

The purpose of completing the PDRI, including the concurrent FEED maturity and PDRI accuracy assessment, is to help stakeholders ensure that they are progressing favorably in early project design before the beginning of detailed design. In order for the maturity and accuracy assessment to provide value, it should be conducted before detailed design commences (Gibson et al. 1995a; Norton and McElligott 1995). If the PDRI reviews are performed during detailed design, it may help with certain design elements; however, the assessment may not have the same impact as if it were completed during FEP. The value of PDRI MATRS that impacts the success of ongoing projects diminishes significantly once detailed design has started (Figure 2.2).

PDRI MATRS is intended to be used up to, and including, PG 3, in any of the following ways: (1) To assess maturity and accuracy at the beginning of FEP to inform the project team on needed management and engineering actions; (2) At the end of detailed scope (PG 3) in order to provide a more in-depth evaluation of FEP and FEED (This will result in a more informed assessment of all elements of the project definition package. It will also identify issues that may impact accuracy of the scope definition effort.); (3) As an audit tool by either internal or external parties looking at FEP and FEED engineering deliverables during any stage of FEP; (4) After FEP or even post project, as a post-mortem evaluation of maturity and accuracy of FEP and FEED (e.g., lessons learned).

For items (1) through (3), the PDRI can assist in the development of a gap list to provide the project team with a path forward to improve the FEP and FEED. The maturity and accuracy assessments of PDRI MATRS can be completed at the same time by the same entity, or split into a stand-alone maturity assessment and accuracy assessment completed by different parties to inform decision makers as needed. For large projects involving several units or work packages, PDRI assessments can be independently used for each one of them. In case of combining the project definition packages for multiple units, care should be taken to review the scope interfaces as these could result in gaps and eventually in poor or incomplete definition (Dumont et al. 1997).

2.5 PDRI Maturity Tool Structure

The PDRI MATRS maturity component consists of three main sections:

I - The Basis of Project Decision;

II - The Basis of Design; and

III - The Execution Approach.

Each section is then organized by categories (15 total) and by elements (70 total) within those categories reflecting the typical deliverables of the project definition package; these elements are also given a score for each definition level. One of the important updates of PDRI MATRS is the provided detailed element and level description to improve consistency and objectivity (Table 2.1). PDRI Maturity element descriptions are stated in the left column of each matrix. Elements should be rated numerically from 0 to 5. The scores range from 0 – not applicable, 1 – complete definition to 5 – incomplete or poor definition, as indicated in the legend at the bottom of the score sheet. The elements that are as well-defined as possible should receive a perfect definition level of 1. Elements that are not completely defined should receive a 2, 3, 4, or 5, depending on their levels of definition as determined by the team. Those elements deemed not applicable for the project under consideration should receive a 0, thus not affecting the final score.

Table 2.1 depicts the typical layout of a maturity element showing how the maturity of each definition level is graded. It should be noted that each element also contains additional technical details unique to each. Basic descriptions of the corresponding definition levels with potential impacts are outlined in the list below:

A. A definition level of 0 indicates that the element is not required for the project and thus will not affect the overall maturity assessment

B. A definition level of 1 indicates that the element is completed, documented, and approved by key stakeholders, minimizing uncertainty, and will not affect cost and schedule estimates when moving to detailed design.

C. A definition level of 2 indicates that the element is mostly complete with minor issues, and should not adversely affect cost and schedule estimates when moving to detailed design.

D. A definition level of 3 indicates that the element is somewhat addressed, with holds for deficiencies, and will more than likely adversely affect cost and schedule estimates through further development.

E. A definition level of 4 indicates that for this element, only initial thoughts have been applied to the design effort, and little or no meeting time or design/consulting hours have been expended. It is expected that elements with definition level 4 have high levels of uncertainty and will adversely impact cost, schedule, and operational characteristics of the project.

F. A definition level of 5 indicates that work on this element has not been started, thus significantly affecting uncertainty around cost, schedule, and operational characteristics of the project.

The basis for determining the level of definition is focused on developing the overall project scope of work such that the project has a higher probability of achieving a cost or schedule estimate at the ±10 percent level at PG 3. This level of definition roughly relates to approximately 25 to 30 percent of design completion for the entire project (AACE International 2005).

Table 2.1 Structure of PDRI Maturity Elements

SECTION	Definition Level					
	N/A	Best		Medium		Worst
CATEGORY	0	1	2	3	4	5
Element *Element description*	Not required for project.	All element descriptions are satisfied and approved by key stakeholders as a basis for detailed design.	Most element descriptions are documented and under review, but not yet approved. There may be minor deficiencies.	Some element descriptions have been defined with holds for deficiencies.	Some initial thoughts have been applied to this element; however, little to no meeting time or design hours have been expended and little has been documented.	Not yet started.
****Renovation and Revamp**** *R&R description*		Items related to R&R have been documented and approved by key stakeholders.	Most items related to R&R have been documented and are under review, but not yet approved.	Some items related to R&R have been identified and are being assessed.	Little or no meeting time or design hours have been expended on R&R items.	

2.6 PDRI Accuracy Tool Structure

The accuracy assessment tool of PDRI is meant to help stakeholders assess 27 factors affecting the quality of the project definition package and FEED. Accuracy involves the people, teams and resources that create the environment where a mature FEP can be developed. The accuracy tool is topologically organized into four types of factors:

1) the project leadership team;

2) the project execution team;

3) project management processes; and

4) project resources.

Each type contains six to eight accuracy factors related to the environment that supports FEP development. Table 2.2 is provided to illustrate how each of the accuracy factors is assessed. The assessor can choose one of five levels ranging from Not Acceptable to High Performing for each of the factors in terms of its description at the time of the assessment. Table 2.3 reflects the list of 27 accuracy factors ranked by their order of importance under each type; the terms with bold fonts highlight the key thoughts in each factor.

Table 2.2 Structure of PDRI Accuracy Factor Assessment

N/A	High Performing	Meets Most	Meets Some	Needs Improvement	Not Acceptable
Not required for project.	Rating a factor *High Performing* indicates the factor's criteria are fully met within the context of their respective category, e.g., project leadership, execution, management, or project resources.	Rating a factor *Meets Most* indicates that the factor's criteria are consistently met and understood with minor deficiencies.	Rating a factor *Meets Some* indicates that the factor's criteria are partially met and without improvement, project success could be in jeopardy.	Rating a factor *Needs Improvement* indicates that the factor's criteria are not consistent in meeting project expectations and without improvement, the project is at risk. Substantial action to meet expectations is required.	Rating a factor *Not Acceptable* indicates that the factor's criteria are consistently below expectations and current performance is unacceptable. Project success cannot be achieved in this current state and actions are required to improve.

Table 2.3 PDRI Accuracy **TYPES** and Factors

1. PROJECT LEADERSHIP TEAM
1a. Leadership team's previous **experience planning, designing and executing** a project of similar size, scope, and/or location, including FEP
1b. **Stakeholders** are appropriately represented on the project leadership team
1c. Project **leadership** is defined, effective, and accountable
1d. **Leadership team and organizational culture** fosters trust, honesty, and shared values
1e. Project leadership team's attitude is **able to adequately manage change**
1f. **Key personnel turnover**, e.g., how long key personnel stay with the leadership team
2. PROJECT EXECUTION TEAM
2a. **Technical capability and relevant training/certification** of the execution team
2b. **Contractor/Engineer's team experience** with the location, with similar projects, and with the FEP process
2c. **Stakeholders** are appropriately represented on the project team (e.g., contractor, operations and maintenance, key design leads, project manager, sponsor) and have a clear understanding of the project scope
2d. Level of **involvement** of design leads or managers in the engineering process
2e. Key personnel **turnover** including the **stability/commitment** of key personnel on the owner side through the FEP process
2f. **Co-location** of execution team members
2g. Team culture or history of the execution team **working together**
3. PROJECT MANAGEMENT PROCESS
3a. **Communication** within the team is open and effective; a communication plan with stakeholders is identified
3b. Organization implements and follows a **front end planning** process (e.g., phase gates, clear requirements), has a **formal structure** or process to prepare FEP, and implements **planning tools** (e.g., checklists, simulations, and work flow diagrams) that are used effectively.
3c. **Priority** between cost, schedule, and required project features is clear
3d. Significant **input of construction knowledge** into the FEP process
3e. Adequate process for **coordination** between key disciplines
3f. **Alignment** of FEP process with **available project information,** including the existence of peer reviews and a standard procedure for updating FEP
3g. **Documentation** of information used in preparing FEP
3h. **Review and acceptance** of FEP by appropriate parties
4. PROJECT RESOURCES
4a. **Commitment** of key personnel on the project team
4b. **Calendar time** allowed for preparing FEP **Management tools** available including technology/software
4c. **Local knowledge** (e.g., institutional memory, understanding of laws and regulations, understanding of site history) and **access** to visit and **evaluate** the site
4d. **Quality** and level of detailed of engineering data available
4e. **Amount of funding** allocated to perform FEP
4f. **Availability of standards and procedures** (e.g., design standards, standard operating procedures, and guidelines)

The PDRI accuracy assessment is of little value unless the user takes action to improve the accuracy environment of the FEP process. Table 2.4 (once again in accordance with the Pareto principle) represents the top five accuracy factors that project teams may want to focus on to best improve their accuracy score. These five factors represent 31 percent of the accuracy total score.

Table 2.4 Five Highest Ranking Accuracy Factors

Rank	Factor	Factor Description	"High Performing" Weight (Unit: %)
1	2a	Technical capability and relevant training/certification of the execution team	7
2	1a	Leadership team's previous experience planning, designing, and executing a project of similar size, scope, and/or location including FEP	6
3	1b	Stakeholders are appropriately represented on the project leadership team	6
4	2b	Contractor/Engineer's team experience with the location, with similar projects, and with the FEP process	6
5	4a	Commitment of key personnel on the project team	6
TOTAL			31

Project teams can use accuracy scores in a number of ways including the following:

- The accuracy scores can be used as a benchmark.
- The accuracy score can be used to assess gaps in the leadership team, execution team, project management processes and project resource allocation related to the FEP effort. For example, if any factor has a rating of Meets Some, Needs Improvement or Not Acceptable the project team should further define this factor or develop a risk mitigation strategy for it. This provides an effective method of

risk analysis, since each factor is weighted relative to the others in terms of importance. Identifying the project's gaps is critical as the project team progresses toward execution, and it should provide "path-forward" action items.

2.7 Performance of the PDRI MATRS

This section discusses the new assessment components, PDRI maturity, FEED maturity, and PDRI accuracy, and what their scores mean to project performance. The section provides insights around what to look for in the PDRI maturity and accuracy scores, and how organizations can learn from these assessments. A low PDRI maturity score represents a project definition package that is well-defined and, in general, corresponds to an increased probability for project success. Higher scores signify that certain elements within the project definition package lack adequate definition.

In a separate synergistic and more recent study, FEED maturity was identified and assessed as a subset of the PDRI dealing specifically with engineering deliverables (Yussef et al. 2019b). PDRI accuracy was added as a new dimension gauging the contextual factors for FEP development. The combined FEED maturity and accuracy assessment was tested on 32 completed large industrial projects (worth a total of $8.83 billion). These included several project types such as chemical plants, refineries, pharmaceutical manufacturing facilities, food manufacturing plants, power plants, pipelines and compression facilities.

A high FEED maturity score (>80) represents a FEED that is well-defined and, in general, corresponds to an increased probability for project success. Lower scores indicate that certain elements within the FEED lack adequate definition. Similarly, a high PDRI accuracy score (>76) represents a project where the accuracy factors related to the project leadership team, execution team, project management processes, and project resources are all aligned. Similarly, lower scores indicate that there are signs of misalignment and potential risk in the quality of FEP. Threshold values for maturity (80) and accuracy (76) were calculated from a stepwise sensitivity analysis of the collected project performance data.

One key outcome of the combined analysis is to be able to plot maturity and accuracy scores on a four-quadrant matrix and correlate these scores with performance. Table 2.5 shows the mean performance for projects in the maturity-accuracy quadrants. Performance outcomes were calculated for cost change and change order performance. Note that change order performance was calculated as the absolute value of changes divided by the total project cost. This calculation outputs the change order performance as a percentage of the total project cost. The sample size for each of the performance areas, as well as the number of projects in each quadrant, is shown in parentheses. In this sample, significant differences were found: large industrial projects with high maturity and high accuracy (HMHA) outperformed those with low maturity and low accuracy (LMLA) by 24 percent on average in terms of cost performance (p-value = 0.007), and by 12 percent on average in terms of change performance (p-value = 0.044).

As a follow-up to the previous research investigation, CII RT 361 went back and contacted all the organizations that provided data for the development of FEED MATRS, and collected the remaining data needed to calculate PDRI scores for the 32 tested projects, resulting in 12 completed PDRI's. The results are provided in the last row of Table 2.5 and show that the maturity and accuracy quadrants are indeed consistent with PDRI maturity scores with an average PDRI score of 324 for LMLA, 210 for high maturity and low accuracy (HMLA), and 163 for HMHA (p-value = 0.001).

Table 2.5 Project Performance based on Maturity Score and Accuracy Scores

Performance	**Maturity Score and Accuracy Score**		
	HMHA (M>80, A>76)	**HMLA (M>80, A<76)**	**LMLA (M<80, A<76)**
Cost* (N=32)	2% below budget (N=11)	6% above budget (N=9)	22% above budget (N=12)
Change Orders* (N=31)	4% of budget (N=12)	9% of budget (N=8)	16% of budget (N=11)
PDRI Maturity Score* (N=12)	163 (N=5)	210 (N=3)	324 (N=4)

*Performance statistically significant ($p < 0.05$)

The evaluations provided here are valid for the samples as given. These samples may or may not be indicative of projects in a specific organization and the samples may be biased because of the size and types of projects making up the sample. However, the statistic analysis results are convincing in terms of performance predictability. FEED MATRS was also tested on current (i.e., in-progress) projects to observe its effectiveness in helping project teams to complete FEP activities. FEED MATRS was tested on 12 projects (from eight organizations) representing over $5.1 billion in expenditures. In addition, PDRI MATRS was tested with 5 organizations on 6 additional projects worth greater than $8 billion in expenditures during real-time planning exercises.

In each case, maturity and accuracy assessments gave the project team an effective method with which to evaluate FEP on the project. These exercises showed the value and capability of the different components of the tool. In general, the feedback from these users was extremely positive. The maturity and accuracy components of the tool performed very well in identifying critical risk issues during the front end planning process, and spurred important conversations about elements not yet considered by the project teams. The accuracy component specifically indicated to management changes to be made to the project teams. It not only helped to assess the quality and adequacy of the technical documentation required, but also provided an opportunity to check the organization's readiness before making a capital investment decision. Both our project execution team and project leadership were quick to see the value and decided to use it going forward in our projects.

Using the new PDRI MATRS tool showed that it takes no more time to perform the PDRI maturity analysis than in the past; in fact, in some cases the assessment went faster, and as a bonus provided a FEED maturity score as well. PDRI MATRS worked very effectively to help the team identify potential gaps, and as in the past, having an experienced facilitator helped. The ability to bracket definition levels allowed teams to move through the 70 PDRI maturity elements fairly quickly, with much of the time spent on the discussions of gaps. The same can be said for the PDRI accuracy assessment, with the team being quite open and honest in its assessment.

Several users reported that the tool is easy to use due to having more clarity on the Maturity element descriptions. Specifically, the PDRI MATRS was extremely helpful on international projects because it allowed for improved clarity for each definition level. Project teams also welcomed the new accuracy component as it helped them see the organization's readiness along with a document available that can be used for discussions with upper management. Some project teams used the accuracy component to evaluate the project and identify needed resources, resulting in the development of a risk matrix with risk mitigation plans.

2.8 Elements Affecting Project Success

The success of the project is determined by project objective and the management effort, which tend to be influenced by cost, time, and quality/performance (de Wit 1988). FEP supports design and construction processes by reviewing early considerations for the project objective, approval process, permits, and uncertainties to improve its cost and schedule performance. Project managers facilitate PDRI MATRS sessions with both owners and contractors at multiple PGs in the FEP process, to reduce the gaps in project delivery. Moreover, PDRI MATRS provides elements weights that considers which items should be significantly considered during FEP. This study identifies cost and schedule elements as project success measures by drawing on expert opinions gathered through the charrette method and compare them with PDRI MATRS maturity elements.

2.8.1 Data Collection Through Charrette

Charrettes are a unique and effective data collection method for academic researchers to collect data from industry respondents by facilitating structured workshops (Gibson and Whittington 2010). Charrettes identify best practices and give insight into key parameters with less researcher bias compared to surveys, source document reviews, and structured interviews, because expertise comes from diverse organizations to discusses their opinions during the workshop. To ensure obtaining diverse opinions and avoiding bias, a variety of stakeholders (e.g., owners and contractors) should be included in charrette. Many practical research projects use this method for the aforementioned reason (CII 2019a; Dicks et al. 2017; Gibson and Whittington 2010).

A charrette to collect opinions from industry was organized with 32 industry practitioners, including owners, government entities, and contractors. The charrette, facilitated by academic researchers from Arizona State University. To understand aspects affecting project success, the charrette aims included discussion points about project experiences and lessons learned about cost and schedule changes. During the group workshop, a discussion began with sample questions and participants expanded their thoughts by feeding off others' input. Many factors can affect project success; therefore, this open session gave participants the opportunity to look at their project. Twenty-eight responses related to cost changes, and thirty responses related to schedule changes, were received. The responses were analyzed based on identified keywords representing overarching themes from PDRI MATRS.

2.8.2 Major Elements Affecting the Cost and Schedule Changes

The question, "What *other* costs were realized on these projects?" was presented to the charrette participants during the session. Table 2.6 shows the 28 collected responses that affect project costs related to each keyword. The sample size of the data is 28 responses, and they contains multiple keywords. Therefore, the study analyzed the result by keywords/themes and collected how many responses were related to the same issues. The results show ten out of 28 respondents experienced cost overrun due to missing overhead or general and administrative (G&A) expense. In addition, equipment and material procurement affected cost overrun significantly. Lastly, commissioning, labor cost changes, and scope creep also affected the project cost.

Table 2.6 shows the PDRI elements measuring these aspects, and the results are further analyzed in the following section. In the same manner, researchers asked participants “Why did the schedule change on these projects?” during the session. The table summarizes the frequency of critical items discussed. The result illustrate procurement as the critical item for appropriate schedule management–for materials and equipment. This is primarily relating to supply chain management issues consisting of various vendors, contracts, original equipment manufacturer design, and delivery schedules. Delays in the detailed design process were the second significant item due to vague FEP processes and basic design deliverables. Risk management items, including off-site conditions, safety incidents, and cash flow constraints, were highly rated as critical items. The list also contains scope changes, permit requirements, commissioning, and site surveys.

Table 2.6 Items Affecting Cost Increase and Schedule Delay

Item List	PDRI Maturity Elements	# of Responses related to Cost Increase (Out of 28 Responses)	# of Responses related to Schedule Delay (Out of 30 Responses)
1. Overhead (or G&A expense)	B2, B3, B4	10	-
2. Equipment	H1, H2, H3	10	-
3. Procurement / Materials	L1, L2, L3	9	11
4. Commissioning	P4, P5, P6	4	3
5. Labor cost	N3	3	-
6. Scope creep	All but changed through scope changes	1	5
7. Detailed Design / Engineering	FEED elements	-	9
8. Uncertainty / Risk management items	N3	-	8
9. Permits	F4	-	4
10. Survey	F2, F3	-	2

The charrette result is not well aligned with the weight of PDRI maturity elements. Figure 2.4 shows the ten highest-ranking PDRI maturity elements. Only the B2, market strategy is overlapped. This difference comes from the different data characteristics that the newly collected data in this study already applied PDRI in their projects. When this study collects opinions from them, the author asked about their current project, which already applied PDRI related methods for their project. Therefore, it is expected that their projects already addressed the majority of PDRI maturity elements during the process.

2.9 PDRI Maturity Elements for Successful FEP

This chapter provides some further studies from the result of the charrette with ongoing projects. However, the limited number of cases in the discussion is not enough to support this chapter strongly. This chapter is included in this dissertation to provide some initial thought for the determined items from the charrette, but more data and practices should be collected in the future to elaborate on the chapter.

2.9.1 Data for Case Study

The ongoing projects data, using PDRI, PDRI MATRS, and FEED MATRS assessment at different PGs of the FEP process, were collected and compared with the 32 completed projects used in the FEED MATRS study for validation. To maintain consistency, the study limited the data sources to only those applying one of these three assessment tools. The identified projects assess PDRI maturity with multiple participants, including both owners and contractors. Table 2.7 shows the 12 ongoing project data sets that were collected and analyzed. Projects were isolated at specific phases in FEP, including one project at PG1, three projects at PG2, and eight projects at PG3. The researchers identified one project as a perfect set of longitudinal data assessing PG 2 and PG 3 (Case 4a and 4b). The data spanned 2014 to 2019, and the project performance results are unavailable because projects were incomplete during the data collection process.

Table 2.7 Ongoing Cases Analyzed

Case #	Project Type	Phase Gate (PG)	Assessment method	Date Assessed	Number of Participants
1	Chemical Facility	PG 1	PDRI MATRS	2017	9
2	Chemical Facility	PG 2	PDRI MATRS	2017	-
3	Plant Expansion	PG 2	PDRI MATRS	2019	-
4a	Gas Facility	PG 2	FEED MATRS	2017	-
4b	Gas Facility	PG 3	PDRI MATRS	2018	25
5	Factory	PG 3	PDRI	2014	-
6	Chemical Facility	PG 3	PDRI	2017	13
7	Mining	PG 3	FEED MATRS	2017	-
8	Manufacturing facility	PG 3	PDRI	2017	-
9	Plant Expansion	PG 3	PDRI	2018	-
10	Ship production	PG 3	FEED MATRS	2018	17
11	Oil Production Facility	PG 3	FEED MATRS	-	-

This case study followed a multiple-case embedded design, which contained multiple contexts and cases with different embedded units of analysis (COSMOS Corporation 1983; Yin 2018). First, the context was constructed from the charrette. In addition, cases had different embedded units, such as PDRI maturity elements, and structured workshops measured these units during PDRI sessions for each case. Therefore, the study compared the PDRI Maturity elements level of description during different steps of FEP, including PG 1, 2, and 3. Each element also compared with 32 completed projects identified during the FEED MATRS study, which measured at PG 3 to test additionally collected ongoing projects are aligned well.

2.9.2 Overhead or General and Administrative Expense

This section discusses the first item listed in Table 2.6 that affect cost overrun. The complexity of construction cost structure is a major reason for cost overrun. Ten out of 28 responses mentioned undefined overhead cost or G&A expense as a significant element affecting cost changes. A clear definition of the cost structure provides a more accurate feasibility study. Figure 2.5 shows the project cost structure, generally, applied in construction projects. Construction cost account for material, labor cost, and overhead. In addition, total project cost consists of construction cost, general and administrative (G&A) expense, and profit for contractors (Jacoby 2007).

Oftentimes, overhead and G&A expenses are misused. Overhead is the cost that cannot be identified specifically against a particular project or activity and is controlled and budgeted at a functional, organizational, or corporate level (NDIA 2018). In contrast, G&A expense means any management, financial, and other expense which is incurred by or allocated to a business unit and which is for the general management and administration of the business unit as a whole. G&A expense does not include those management expenses whose beneficial or causal relationship to cost objectives can be more directly measured by a base other than a cost input base representing the total activity of a business unit during a cost accounting period (U.S. General Services Administration Federal Government Computer System 2019). For example, the G&A expense usually is ten percent of the construction cost, with profits estimated more than nine percent of the sum of labor cost, expenses, and overhead from the US market (Hoare, David 2013; Stone 2013).

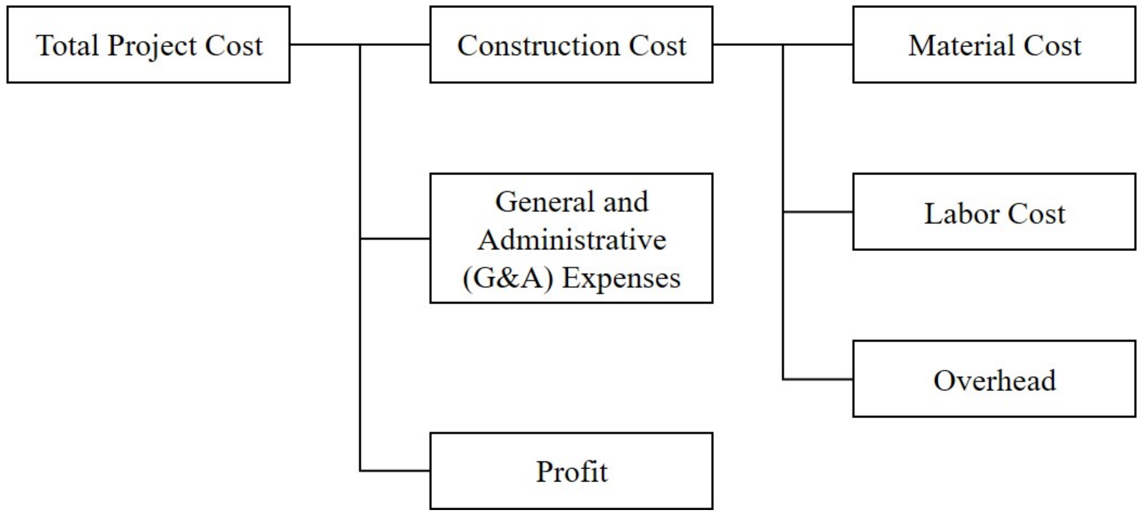

Figure 2.5 Project Cost Structure

The cost structure significantly affects the total project cost and cost overrun because unidentified cost structure affects the investment return of the project. According to guidelines from the Association for the Advancement of Cost Engineering (AACE) International (2005), capacity factored, parametric models, judgment, analogy, or equipment factored are the typical estimating methods used to estimate project cost during the concept screening and feasibility study phase (Class 4 and 5 estimation). If these experimental cost estimation models are used, it is important to understand which "costs" are included in the model. Usually, the cost estimation models are analyzing partial construction cost, so they are not including G&A expense and profit (e.g., Kim and Kim 2010). If G&A expense and profit are not included when comparing the alternative projects, the total cost may differ by about 20, and decision making can be significantly affected.

This overhead can affect PDRI MATRS, specifically when it assesses the business objective. The PDRI MATRS includes cost considerations from B2 to B4; the elements' definitions are presented below (CII 2019).

- *B2. Market Strategy:* A market strategy has been developed and clearly communicated. It identifies the driving forces (other than safety) for the project and specifies what is most important from the viewpoint of the business group.
- *B3. Project Strategy:* The project strategy has been defined. This strategy supports the market and/or business strategy or drivers.
- *B4. Affordability/Feasibility:* Items that may improve the affordability of the project should be considered during scope development and communicated to the project team.

B2, market strategy, estimates how much profit can be produced from the project. B3, project strategy, delegates cost, schedule, quality, environmental sustainability, security, and others. B4, project feasibility, considers diverse factors influencing the project's affordability and overall scope. The cost structure should be considered in B3, but its impact is aligned at these three elements.

Table 2.8 compares the average PDRI definition levels for B2 to B4 elements by PGs of ongoing projects (left side), and shows the maturity element scores for HM and LM at PG 3 for completed projects (right side), which were collected in the FEED MATRS and PDRI MATRS studies. Note that B2 to B4 are not included in the FEED maturity assessment; therefore, the data set only allows 32 out of those 12 completed projects are available in the analysis. In addition, as discussed in the tool structure, a lower definition level means the element is defined more clearly.

The average definition level of PG2 and PG 3 of ongoing projects represents market strategy, project strategy, and feasibility is well defined through the FEP process. Project managers should find and address gaps in the project, such as production costs, operating costs, and cost details from engineering based on timely analysis of the project progress. One project located at PG1 in Table 2.8 was assessed that it is well defined at the stage. However, achieving definition level 1 or 2 is technically impossible at the beginning of the FEP process because the accurate cost estimation method is not available in this stage (AACE International 2005). To address these inconsistent scoring mechanisms of traditional PDRI analysis due to different interpretation from facilitators, PDRI MATRS provides detailed descriptions of elements and definition levels.

Table 2.8 PDRI Score on Business Objectives

	Ongoing Projects			Completed Projects (N=12)	
	PG 1 (N=1)	**PG 2 (N=2)**	**PG 3 (N=4)**	**HM (N=8)**	**LM (N=4)**
B2	1.00	3.00	1.50	1.14*	1.33*
B3	2.00	3.00	1.50	1.50*	1.75*
B4	2.00	3.00	1.50	1.43*	2.25*

Note: Low score shows better definition; range = 1 to 5; and * shows it is statistically significant, $p < 0.05$.

2.9.3 Equipment

Industrial projects are typically delivered by engineering, procurement, and construction (EPC) methods. EPC projects have a high portion of the equipment price ratio, lending to difficulty negotiating price changes in the middle of projects. For Black and Veatch Corporation (2012), their cost data reports significant ratio differences in capital cost breakdowns. The report summarizes a nuclear power plant costs consist of 47.6% for yard, cooling, and installation cost; 19% owner's cost; 17.5% equipment cost; and 15.9%

EPC management cost. For small plants, such as the gas turbine power plant presented in Black and Veatch's report, 40% of total costs are for equipment. These different ratios could be attributed to the type of plants, but underlying price differences are governed by the equipment prices in plant construction.

The PDRI tool contains the equipment scope category determined from H1 to H3 maturity elements. The element names and description follow.

- *H1. Equipment Status*: Has the equipment been defined, inquired, bid tabbed, or purchased?
- *H2. Equipment Location Drawings*: Equipment location/arrangement drawings identify the specific location of each item of equipment in a project.
- *H3. Equipment Utility Requirements*: A tabulated list of utility requirements for all equipment items should be developed.

The case study results for ongoing projects are presented on the left side of Table 2.9. The table provides the average definition levels of H1 to H3 that are improved throughout timeline. However, the right side of Table 2.9, which illustrates the definition level differences between HM versus LM cases of completed projects, present the gap between ongoing projects and completed projects that are assessed at the same point. Specifically, the assessment results of ongoing projects at PG3 are close to definition level 3 for H1 and H2, and H3 is close to definition level 2, but completed projects have 1 level lower score, which represented better definition.

Table 2.9 Average of Definition Level

	Ongoing Projects			Completed Projects (N=32)	
	PG 1 (N=1)	**PG 2 (N=3)**	**PG 3 (N=8)**	**HM (N=20)**	**LM (N=12)**
H1	4.00	3.33	3.00	2.10*	2.92*
H2	3	2.67	2.75	1.85*	2.92*
H3	2	3	2.38	1.70*	2.92*

Note: Low score shows better definition; range = 1 to 5; and * shows it is statistically significant, $p < 0.05$.

Table 2.10 presents the description of Level 2 and 3 for H1 to H3. H1, equipment scope, shows that the difference between level 2 and 3 more detailed information for both major and minor equipment and they are ready for purchase. It shows that level 2 have significantly less risk compared to level 3. H2, equipment location drawings, presents that level 2 as in review status and level 3 is under development. H3, equipment utility requirements, for level 2 is mostly defined and documented, compared to level 3 is just defined. All elements have significantly less risks to be changed if they are located under level 2 category. This definition level clearly shows that the elements located under H1 to H3 should be defined as similar to HM scores regarding Table 2.9 to avoid cost overrun.

Table 2.10 Equipment Level Description

Maturity Elements	Definition Level (DL)	Level Description
H1	DL 2	All major and most minor equipment items have been defined, inquired, bid tabbed, and ready for purchase.
	DL 3	Most major and some minor equipment items have been defined, inquired, and bid tabbed.
H2	DL 2	Equipment location drawings are mostly complete and issued for review.
	DL 3	Equipment location drawings are developed, with some holds for deficiencies.
H3	DL 2	Most equipment utility requirements are defined and documented to match up with the supply conditions, but are missing minor details.
	DL 3	Some equipment utility requirements are defined.

If the vendors are determined later, the project can face obstacles and it will cause losing its chance to negotiate the equipment cost from vendors as well as the delay in the design and engineering process. As found from charrette, the detailed design process is a primary schedule delay factor while basic design and equipment issues delay the detailed design process. It is important to apply these results to construction practice. HM projects have a higher success rate, and they provide a detailed assessment of the equipment during FEP. The datasets collected from each PG exposed a gap in equipment status and location drawing during the FEP process, while charrette results confirmed these issues are correlated with delays in the detailed design process. Determining the potential equipment providers among a list of alternatives is one of the essential risk management items during FEP.

2.9.4 Procurement / Materials

Procurement is a core element for the success of industrial projects. In the charrette results, procurement ranked third in priority for cost consideration and first in in terms of impact on the schedule. The procurement process is complex in the construction industry because many vendors and providers are linked to one another. For example, the late delivery of a major equipment affects the rest of the construction schedule, resulting in possible derailment of project success. Therefore, considering procurement within the supply chain is required. The PDRI MATRS provides three major items to consider with regards to procurement.

- *L1. Identify Long Lead/Critical Equipment and Materials*: Identify engineered equipment and material items with lead times that impact the detailed engineering process for receipt of vendor information or that impact the construction schedule with long delivery times.
- *L2. Procurement Procedures and Plans*: Specific guidelines, special requirements, or methodologies for accomplishing the purchasing, expediting, delivery, and security of equipment and materials required for the project.
- *L3. Procurement Responsibility Matrix*: A procurement responsibility matrix denoting authority and responsibility of key stakeholders is developed.

Table 2.11 shows the average definition level on L1 to L3. Note that procurement strategy maturity elements are only available from cases using the PDRI assessment; cases using FEED MATRS do not have an evaluation for these items. Therefore, analysis on completed projects only contains 12 projects. The case studies show procurement strategy maturity elements are well defined through the FEP process. At the PG 3, all three items have high proximity to Definition Level 1 and high rates in delivering a successful project.

However, two cases under PG3, ongoing projects, showed high definition level due to site preparation issues and miss-planning related to the shop drawing inspection. The procurement issues cannot be managed from one side, because various parties are involved in this action. For better procurement planning, the following items must be considered: the owner's approval, matching the construction plan with shop drawings, confirmation of the change control requirements, cost and schedule approvals, and delivery methods. In addition, preparing an approved vendor list during FEP will significantly reduce the risks during the engineering and construction process.

Table 2.11 Average of Definition Level on L1 to L3

	Ongoing Projects			**Completed Projects (N=12)**	
	PG 1 (N=1)	**PG 2 (N=3)**	**PG 3 (N=8)**	**HM (N=8)**	**LM (N=4)**
L1	3.00	3.50	1.50	1.13*	1.50*
L2	1.00	3.00	1.75	1.38*	2.50*
L3	1.00	3.50	1.50	1.50*	2.50*

Note: Low score shows better definition; range = 1 to 5; and * shows it is statistically significant, $p < 0.05$.

2.9.5 Commissioning

Start-up and commissioning are major items debated between owners and contractors (O'Connor et al., 2016). Most contractors consider the commissioning category as perilous terrain because it has many uncertainties, and it is difficult to prove a particular party is at fault or attribute specific events to a party. There are many uncertainties surrounding start-up and commissioning performance, therefore, clear terminology is required in the contract. The charrette results identify that commissioning significantly affects both cost and schedule.

In the PDRI Project Execution Plan category, P4 to P6 considers commissioning and turnover. The PDRI MATRS defined elements of the commissioning phase as follow:

- *P4. Pre-Commissioning Turnover Sequence Requirements*: The owner's required sequence for turnover of the project for pre-commissioning and start-up activation is developed.
- *P5. Start-up Requirements:* Start-up requirements are defined and responsibility established. A process is in place to ensure that start-up planning will be performed.
- *P6. Training Requirements:* Training requirements are defined and responsibility established.

The definitions of these elements clearly show a plan must be prepared for the commissioning and start-up. However, the case study results in Table 2.12 illustrate that both ongoing and completed projects do not determine commissioning issues clearly during the FEP process. Table 2.12 shows that, during the FEP process, projects did not consider commissioning above definition level 3 during FEP. Moreover, HM completed projects also are positioned Level 3 maturity. The descriptions of Maturity Level 3 for each element shown below present that all items leave significant gap with ideal condition.

- *P4:* Some of the shutdown/ turnaround requirements have been developed with open items.
- *P5:* Some of the pre-commissioning requirements are developed with holds for deficiencies.
- *P6:* Some start-up requirements have been identified.

Table 2.12 Average of Definition Level on P4 to P6

	Ongoing Projects			Completed Projects (N=12)	
	PG 1 (N=1)	**PG 2 (N=3)**	**PG 3 (N=8)**	**HM**	**LM**
P4	2.00	3.67	3.29	3.00* (N=20)	3.92* (N=12)
P5	3.00	3.67	3.38	2.79* (N=20)	4.08* (N=12)
P6	4.00	4.50	3.40	2.83* (N=8)	3.50* (N=4)

Note: Low score shows better definition; range = 1 to 5; and * shows it is statistically significant, $p < 0.05$.

The study's results clearly show project experts have high expectations of procurement items, yet most projects did not address it ideally during FEP. Specifically, contractors experience high pressure during commissioning, and any unexpected events during this stage impact can range from schedule delays to "liquidated damage" by contract (Cagno et al. 2002; Hossen et al. 2015). To avoid contract termination, it is important to define turnover and start-up requirements, along with the responsibility of each party. For example, if the ramp rate on a generator is specified in the contract, the contractor should clarify whether the responsibility of this specification lies with themselves or with the boiler provider. In the contract, liquidated damage payments must be explicitly defined, and contractors can discuss it with owners to negotiate an achievable schedule. Lessons learned regarding commissioning includes extensive preparation and review of the contract.

2.9.6 Scope Creep

Most projects experience scope changes throughout the project's duration. The changes at the beginning of FEP do not affect the schedule of the project significantly, but any scope creeps after FEP significantly impact cost changes and schedule either positively or negatively. Therefore, early confirmation of project scope is important to keep the project on track. Table 2.13 depicts the impact of scope changes in the definition level for Case Number 4 in Table 2.7. The project faced two different scope changes. First, the project site was initial designed in five various locations, but one location was excluded in the final construction. Second, the project's initial stakeholders consisted of government agencies only, but commercial customers were included after PG 3. The project thus required additional infrastructure to match the commercial customer's expectations. Therefore, the elements in Table 2.13 expanded to a larger definition level, meaning they required more work. For example, future expansion plans, project design criteria, process flow, and heat and material balance needed to be updated for the additional infrastructure for commercial customers, and survey and soil tests were also delayed due to the late site confirmation.

Table 2.13 Scope Changes on Case #4

Elements	**Definition Level**		**Note**
	PG2	**PG3**	
B6. Future Expansion Considerations	0	2	Scope Changes: Include commercial customers requires additional changes.
D2. Project Design Criteria	1	3	Scope changes: Including commercial customers requires additional changes.
F2. Survey & Soil Tests	1	3	-
G1. Process Flow Sheets	1	3	PFD is in development.
G2. Heat & Material Balances	2	3	Scope changes: Potential additional site is removed and work plan changed.

Note: Low score shows better definition; and range = 1 to 5

Scope changes are unavoidable for comprehensive and acceptable project planning. Cho and Gibson (2001) suggest a building project scope definition, using the PDRI, which includes initiation, scope planning, scope definition, scope verification, and scope change control. In addition, PDRI is beneficial for defining project scopes in the early stage of the project by providing structured assessment (Bingham and Gibson 2017; Collins et al. 2017; Dicks et al. 2017; Dumont et al. 1997). This case study illustrates that scope change must be controlled, and, if scope change occurs, the PDRI assessment should be re-organized to re-address relevant changes. Furthermore, potential issues related to scope changes are tracked through risk register and discussed through engineering processes.

2.9.7 Uncertainty / Risk Management / Labor Cost / Permits / Site Survey

Construction projects have many uncertainties due to their complexity and assortment of tasks involved (Gibson et al. 2006). Therefore, implementing risk registration at the pre-planning stage ensures the degree, type, and visibility of risk management are proportionate to the project's risk factors, priorities, and stakeholders (PMI 2017). During the charrette, participants used different ways of describing and expressing issues, but they were all connected to risk management issues. For example, three responses mentioned labor cost increasing total cost, and four responses were related to permits causing project delay. Lastly, two responses reflected how the site survey affects delays.

The definitions of related PDRI maturity elements are presented below.

- *F2. Surveys and Soil Tests:* Surveys and soil test evaluations of the proposed site should be developed.

- *F3. Environmental Assessment:* An environmental assessment should be performed for the site to evaluate issues that can impact the cost estimate or delay the project.
- *F4. Permit Requirements:* A permitting plan for the project should be in place. The local, state or province, and federal government permits necessary to construct and operate the unit/facility should be identified.
- *N3. Risk Analysis:* A risk analysis focusing on cost and schedule has been performed and a process is in place to ensure that periodic risk analysis is conducted. Major project risks need to be identified and quantified, and management actions are taken to mitigate problems.

Table 2.14 shows the definition levels of each item at the PGs and the validation of completed cases. The ongoing projects have level 2 definition level on surveys, soil test, and environmental assessments during the PG2, which means that these items are defined quite early phase of FEP. The completed projects show HM projects drives risk-related items, F1 to F3, defined about definition level 1 at PG3. In addition, completed cases for HM projects show N3 only reduces to Definition Level 2, where a risk analysis and mitigation program and plan have been documented but not yet approved by key stakeholders (e.g., the business unit, engineering, project management, operations and maintenance, and construction groups).

Table 2.14 Average of Definition Level on F2 to F4 and N3

	Ongoing Projects			Completed Projects (N=12)	
	PG 1 (N=1)	**PG 2 (N=3)**	**PG 3 (N=8)**	**HM (N=8)**	**LM (N=4)**
F2	4.00	2.00	1.57	1.70	2.33
F3	1.00	2.00	1.75	1.80	2.33
F4	3.00	3.00	2.00	1.58	2.33
N3	2.00	3.00	2.25	2.00	3.25

Note: Low score shows better definition; range = 1 to 5; and * shows it is statistically significant, $p < 0.05$.

In addition, labor cost is included in risk management items. For example, in the US, the Davis-Bacon Act restricts the minimum wages to be paid to various classes of laborers and mechanics employed under contract (US Department of Labor 2019). Congress added prevailing wage provisions to approximately 60 statutes, which assisted construction projects through grants, loans, loan guarantees, and insurance. These "related Acts" involve construction in areas like transportation, housing, air and water pollution reduction, and health. The minimum wage rate changes annually, sometimes sharply based on the economic conditions; therefore, it should be monitored as a risk item. Internationally, labor cost should be determined more carefully because some nations change minimum wages aggressively, depending on their political situation. For example, Egypt’s minimum monthly wage was increased by 66% in 2019 to assuage economic hardships (Saba 2019; Trading Economics 2019).

2.9.8 Detailed Design

Nine of 30 total respondents stated detailed design drives the project schedule delay for their projects. Some respondents provided some more details, such as unclear engineering deliverables and vendors’ late involvement become critical delay factors at the detailed design stage. Usually, engineers determine PG 3 as the point at which 30% design completion has been reached, and at this point detailed design started. This means that any undescribed changes after PG 3 can cause a delay in detailed design. Insufficient basic design, which is related to a significant rework of engineering, late engineering deliverables, inefficient field surveys, vendor responses, and equipment delivery, were identified as the major reasons for project schedule changes during the charrette. Therefore, it is not an exaggeration the items discussed in previous sections are all related to this issue.

The detailed design phase involves planning an achievable execution plan which considers engineering deliverables (Govindaraj and Ramasamy 2005; Tribelsky and Sacks 2010). Therefore, FEED MATRS research only focuses on engineering deliverables from PDRI and allows project managers and engineers to focus only on these items after PG 3. This means that all other alternatives and planning must finish before PG 3. Using the PDRI MATRS helped reduce workload during the detailed design phase by preparing relevant information in the early stages of the project. The appropriate use of PDRI MATRS will entirely improve the quality of design documents (Gibson and Gebken 2003).

2.10 Impact of the Research

The impact of the study is discussed in detail, which developed from the result of Figure 2.6. The figure shows the performance of PDRI based on 32 completed project samples. Average cost change on the HMHA quadrant is two percent below budget and its first to third quarter variation is 18 percent. On the contrary, projects under the LMLA quadrant have 22 percent over budget on average, and their cost variation from first to third quarter is 18 percent. The cost variation clearly shows that if the project is aligned in the HMHA quadrant, there should be a better chance to reduce impacts from uncertainties.

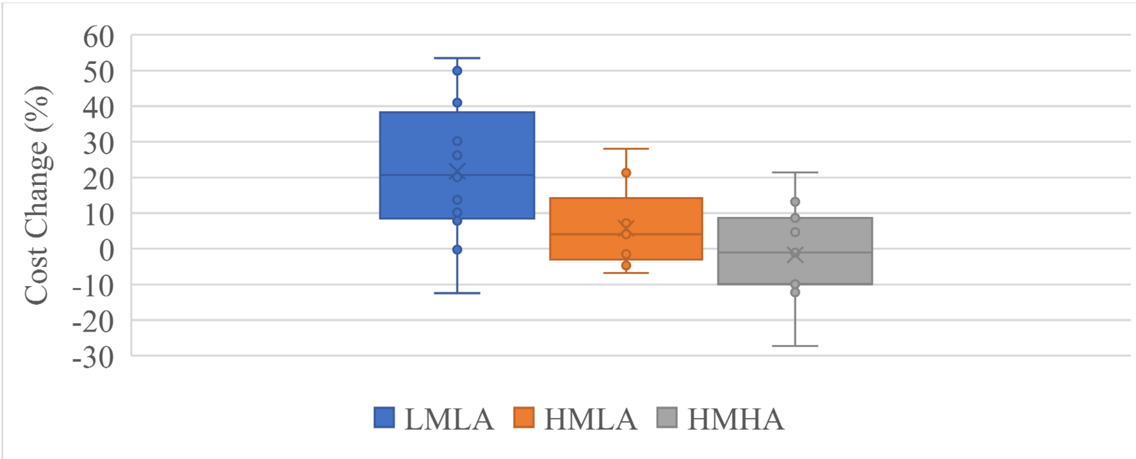

Figure 2.6 Performance of PDRI MATRS

2.11 Conclusion

PDRI MATRS helps to implement front end planning by providing a more consistent mechanism to evaluate the level of definition of engineering design and other scope definition deliverables. PDRI maturity and accuracy scores are but one result of using PDRI MATRS. Experience has shown that the gaps identified during the assessment as well as the team alignment that occurs, are just as valuable, if not more valuable than the score.

PDRI MATRS can benefit owners, developers, designers, and contractors. Facility owners, developers, and lending institutions can use it as an assessment tool for establishing a comfort level at which they are willing to move forward on projects. Designers and contractors can use it as a means of negotiating with owners in identifying poorly defined project scope definition elements. PDRI MATRS provides a forum for all project participants to communicate and reconcile differences using an objective tool as a common basis for project scope evaluation. It also provides excellent input into the detailed design process in the form of the FEED maturity measure and a solid baseline for design management.

CII research has shown that the PDRI, along with FEED maturity and PDRI accuracy metrics, can effectively be used to improve the predictability of project performance. However, the PDRI alone will not ensure successful projects. When combined with sound business planning, alignment, and good project execution, it can greatly improve the probability of meeting or exceeding project objectives.

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3. USE OF PROJECT CONTROL DATA: PLANNING, DESIGN, AND CONSTRUCTION STAGE

3.1 Abstract

Supporting project management decisions using an earned value management system (EVMS) provides significant benefits to control project cost schedule and for both owners and contractors. However, there is a lack of a holistic approach to understand the maturity of an EVMS in accordance with established guidelines. This chapter analyzes existing EVMS studies coupled with performing an industry survey to propose management considerations for successful EVMS implementation and execution. The research results in multiple recommendations that can lead to a more reliable EVMS, including the need for a parallel assessment considering non-technical elements such as the organizations' management culture, is essential to improve EVMS.

3.2 Introduction

Measuring the success of a project is complex due to its time dependence and the different meanings of success for various stakeholders (de Wit 1988). It is important to reach a consensus on what success entails, that both owners and contractors can agree on. Generally, the success of project management is often referred to as the variance from cost and schedule baseline estimates (Bryde et al. 2018). The concept of cost/schedule control system criteria (C/SCSC) was first introduced in 1967 by U.S. federal government agencies (Anbari 2003; Christensen 1994). Currently, the concept is called earned value management (EVM). Various agencies apply EVM for managing their projects and programs, with broad sector applications including construction, software development, and weapons research and development (Department of Defense 2017; Naderpour and Mofid 2011; Staley et al. 2002).

The EVM system (EVMS) is a powerful tool that supports project management, especially for unique, complex, and large projects. Bryde et al. (2018) state that a well-designed and well-operated EVMS can improve the likelihood of project success. However, EVMS implementation and execution depend heavily on the project at hand and are highly influenced by the project's organizations, project team, project manager, and so on. To improve and standardize EVMS, International Standard Organization (ISO) 21508 and National Defense Industrial Association (NDIA) Integrated Program Management Division (IPMD) provide standard guidelines to support EVM application for successful project and program management (ISO 2018; NDIA 2011). Such documents bring needed guiding principles to the EVMS field of study. However, even guidelines are still subject to varying interpretations.

A reliable EVMS is often a system that it is compliant, uses best practices, follows established guidelines, and is effective to manage the project. The EVMS needs to be sufficiently mature before project execution. The maturity of EVMS can be defined as the degree to which a system serves as the basis for an effective EVMS. Moreover, the environment in which an EVMS is implemented can also impact the degree of confidence in the outputs of the system and effective program/project management and decision making, which is critical for project success.

The primary objective of this study is analyzing the current practices and challenges of EVMS through a literature review and an industry survey. This chapter summarizes and analyzes the literature that focuses on improving the reliability of EVMS in order to integrate the existing knowledge on the topic, while highlighting the gaps in the literature. The survey of EVMS experts highlights the gaps and requirements for appropriate utilization of EVMS. The findings of this chapter will provide a basis for developing an EVMS maturity and environment total rating (METR).

3.3 Background on EVMS and Its Maturity and Environment

A thorough literature review was conducted to investigate the body of knowledge around EVM and EVMS. It also offered a solid basis to develop key definitions and to develop the survey. The author and the research team referred to the various sources that exist in the literature to form the definitions for EVM and EVMS (e.g., Department of Defense 2017; ISO 2018; NASA 2018; NDIA 2011). The definitions often had similarities, but some were worded differently. Combining these definitions while working with a research team of EVMS industry experts, the team defined:

- *EVM* as the use of performance management information, produced from the EVMS, to plan, direct, and control the execution and accomplishment of contract/project cost, schedule, and technical performance objectives; and
- *EVMS* as an organization's management system for project/program management that integrates a defined set of associated work scopes, schedules, and budgets for effective planning, performance, and management control.

Figure 3.1 illustrates the basics of an EVMS that is made up of nine control accounts (CA), which are shown as yellow boxes. The performance measurement baseline (PMB), which is also called present value (PV) or budgeted cost for work scheduled (BCWS) is the S-shaped curve shown in red in Figure 3.1. The PMB is developed based on the CAs, undistributed budget consisting of the activities not yet distributed to a CA, and summary level planning packages (SLPPs). The contract budget base (CBB) or project budget base (PBB) is the sum of the PMB and management reserve (MR), which is used for management control purposes. By comparing PMB versus the blue-colored curve of earned value (EV) or budgeted cost for work performed (BCWP), project managers can compute schedule variance (SV). Also, by comparing the blue-colored EV curve versus the green curve, which is the actual cost (AC) or actual cost of work performed (ACWP), project managers can compute the cost variance (CV). These values allow them to calculate an estimate at completion (EAC), cost variance at completion (VAC), and estimated completion date, all of which are shown on the right side of Figure 3.1. With this information, project managers can control their project and develop recovery plans as needed.

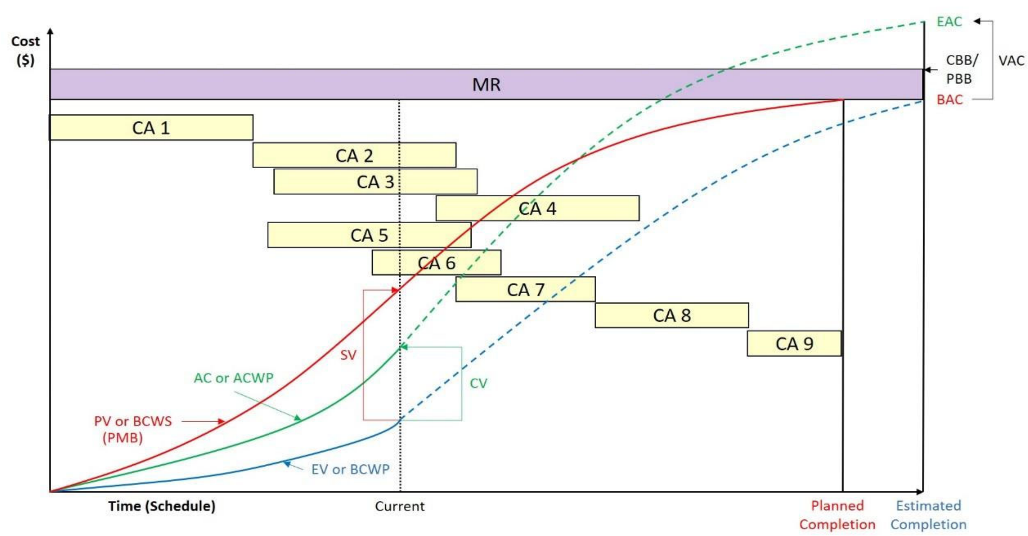


Figure 3.1 Earned Value Management System Basics (Adapted from Department of Energy (DOE) 2019)

The maturity of an EVMS, and the environment in which is it used, can impact the system's reliability and effectiveness to provide accurate cost and schedule data. The author adapted the definitions of "maturity" and "environment" from the Construction Industry Institution (CII)'s recent work on front end planning. The definitions used in this study are as follows:

- *EVMS maturity* is the degree to which an implemented system, associated processes, and deliverables serve as the basis for an effective and compliant EVMS.
- *EVMS environment* is the conditions (i.e., people, culture, practices, and resources) that enable or limit the ability to manage the project/program using the EVMS, serving as a basis for timely and effective decision-making.

Figure 3.2 shows the project life cycle containing business planning, front end planning, design, execution, and facility operation. According to the acquisition process of DOE and Department of Defense (DoD), the EVMS is operated and maintained throughout the project lifecycle, including front end planning, design, and execution phase (National Nuclear Security Administration (NNSA) 2016; Defense Acquisition University (DAU) 2020). A schedule can be estimated from milestones and historical data. A mature EVMS should include accurate project schedule estimation using acknowledged productivity sources with an understanding of available resources. The EVMS will then be used throughout the project to measure progress and make informed decisions.

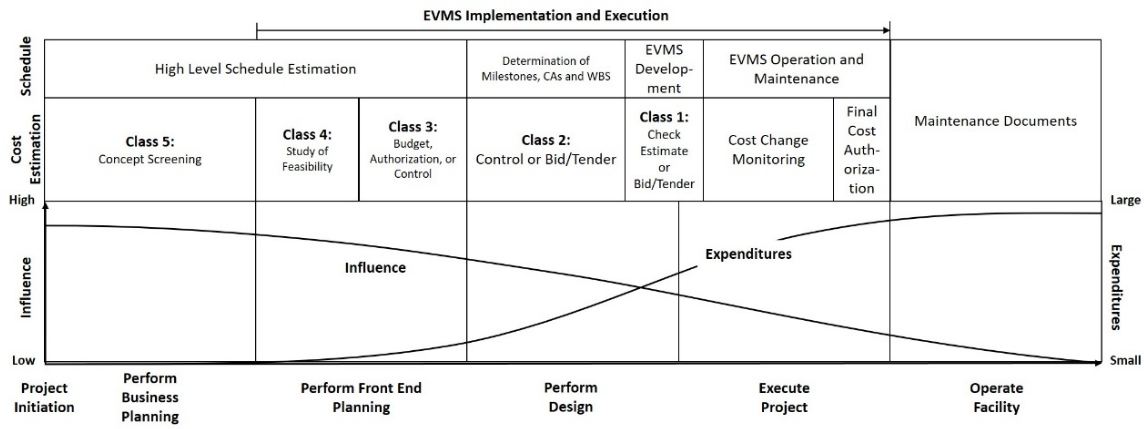


Figure 3.2 Maturity of EVMS (Adapted from AACE International 2005 (middle) and Gibson et al. 1995 (bottom))

EVMS maturity can be determined by looking at the nine distinct processes of EVMS implementation and execution, in accordance with EIA-748-D (NDIA 2011; NDIA 2020). Additional process is identified from U.S. department of defense, which is critical to manage risks (DOE 2012; DOE 2018). Figure 3.3 shows the EIA-748-D guidelines, ordered to reflect the EVMS implementation and execution phases. The ten processes that make up EVMS implementation and execution, according to NDIA (2011) are: (A) Organizing, (B) Planning and Scheduling, (C) Budgeting and Work Authorization, (D) Accounting Considerations, (E) Indirect Budget and Cost Management, (F) Analysis and Management Reporting, (G) Change Control, (H) Material Management, (I) Subcontract Management, and (J) Risk Management.

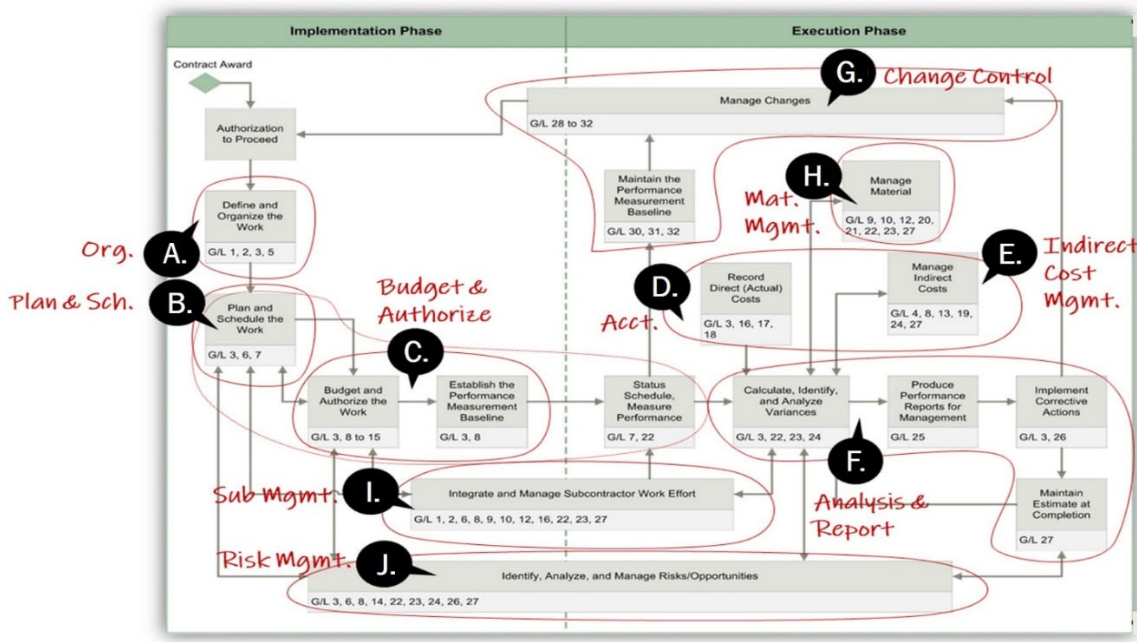


Figure 3.3 Applying the Guidelines to the Project Phases (NDIA 2011)

The 10 EVMS processes and their 32 guidelines help gauge the maturity of an EVMS. In parallel, the environment in which the EVMS is used may have as much impact on the system's effectiveness. CII (2019)'s project definition rating index maturity and accuracy total rating system (PDRI MATRS) recent development, discussed in the Chapter 2 of this dissertation, shows there are other contextual factors, beyond the technical development process, that can significantly impact project performance (CII 2019; Yussef et al. 2019). To address these non-technical factors, a potential "EVMS environment" assessment is proposed, building on what the CII front end engineering design (FEED) MATRS and PDRI MATRS research teams have developed.

CII's accuracy factors gauge four main areas: (1) the project leadership team, (2) project execution team, (3) project management processes, and (4) project resources. Bryde et al. (2018) state that the EVMS operates smoothly when the client invests in adequate training and awareness in the use of the EVMS for all members of the project team. This aligns with the PDRI MATRS' identified accuracy areas. In addition, the publication also states that leadership is one of the key factors for successful EVMS implementation (Bryde et al. 2018). This environment assessment factor is in line with Kim et al. (2003)'s findings where the experience of project leaders was found critical as they train and build the right teamwork environments. Kim et al. (2003) found that it is required to make sufficient effort to address environment factors (regardless of whether the term "environment" is used or not) in order to successfully adopt EVMS. Gonzales (2016) states that the consideration planning, organizing, and managing resources is the key to bring about the successful completion of specific project goals and objectives. Based on the initial analysis of literature, this study identified four EVMS environment overarching categories: culture, people, practices, and resources.

3.4 Research Method

To determine the current state of knowledge and state of practice of EVMS maturity and environment, this study performed a comprehensive literature review and a large industry survey. Figure 3.4 shows the research process followed in this study. First, the comprehensive literature review analyzes 395 published documents to understand the existing knowledge on EVMS, as well as trends and gaps. Second, an industry survey was developed and distributed to EVMS industry experts to determine the current state of practice of EVMS in the industry. Third, the survey responses were collected during the third quarter of 2019, and the data are analyzed using both quantitative and qualitative methods.

Step 1	**Conduct a Comprehensive Literature Review** • Review the literature • Draft definitions for EVMS, EVM, EVMS maturity and environment • Identify research trends of EVMS studies by analyzing 395 documents • Determine gaps in EVMS maturity and environment body of knowledge
Step 2	**Develop Industry Survey** • Draft the EVMS questionnaire • Review with Industry practitioners • Create the survey on Qualtrics™ to automate the process, categorized as follows: 1. General Agreement of EVM and EVMS terminology and definitions 2. The current practices of EVMS maturity assessment 3. Challenges to applying EVMS 4. Importance of EVMS Processes 5. EVMS Environment factors
Step 3	**Collect Data and Analyze Results** • Survey administered over three months from August 1, 2019 to October 31, 2019 • 364 responses recorded, of which 294 useable responses are analyzed and discussed ✓ Rank order questions are analyzed quantitatively ✓ Other questions are analyzed using qualitative keyword analysis

Figure 3.4 Research Process

The major objectives of the EVMS survey were to:

(1) Align the definitions of EVM and EVMS that can be used in various industries.

(2) Determine the industry's state of practice on EVMS maturity assessment.

(3) Gauge the industry's state of practice around EVMS implementation, in terms of challenges, processes, and contextual EVMS environment factors.

The survey contained 23 questions, as summarized in Figure 3.5. Detailed survey questions are included in APPENDIX A of this dissertation. All survey questions were tested and verified with 27 research team members that are EVMS industry experts representing both owners and contractors.

One interesting series of questions involved rank ordering processes, factors, and challenges, in order of importance. The quantitative analysis method applied is numerically measuring the relative weight of given factors, in order to rank the top factors relative to one other. Equation (1) shows the relative weighted average calculation of factors.

$$\overline{x_n} = \frac{\sum_{i=1}^{n} w_i x_i}{N \times mean\ score \times rank\ chices} \qquad (1)$$

$\overline{x_n}$: Weighted Average;

w_i: Frequency of Answer;

x_i: Score of Answer; and

N: Total Number of Responses

For example, out of 277 respondents (shown as "*N*" in equation 1), 177 respondents (shown as w_i in equation 1) ranked the factor "Leadership/manager attitudes towards EVMS" when asked to rank top three most challenging factors that affect EVMS. These ranks were put into an Excel™ spreadsheet, and each rank was translated to an importance score. Challenging factors ranked first received a score of 3, factors ranked second received a score of 2, third received a score of 1, and factors that were not ranked received a score of 0. Scores were then aggregated across all respondents, and an average score for each challenging factor was generated. The "Leadership/manager attitudes towards EVMS" factor received a score of 2.401 (shown as x_i in equation 1). Equation (1) was then used to calculate the relative percentage weights for all factors (shown as $\overline{x_n}$ in equation 1). In the case of the "Leadership/manager attitudes towards EVMS" factor, this resulted into 25.6 percentile (the result of (177x2.401) / (277x2x3)). All the factors' relative percentage weights sum up to 100.

Demographics

- Q1. Please indicate your Employer.
- Q2. Please provide your typical employment role.
- Q3. How many years of work experience do you have in total?

EVM Definition

- Q4. Does your organization have a standardized definition of *EVM*?
- Q5. Since you answered *Yes on Q4, p*lease provide your organization's definition of *EVM*.
- Q6. Below is our research team's working definition of *EVM*: Do you agree with this *EVM* definition?
- Q7. Since you answered *No on Q6*, please provide comments.
- Q8. Does your organization have another term that is used in place of the term *EVM*?
- Q9. Since you answered *Yes on Q8*, please provide your organization's other term that is used in place of the term *EVM.*

EVMS Definition

- Q10. Does your organization have a standardized definition of *EVMS*?
- Q11. You answered *Yes on Q10*; please provide your organization's definition of *EVMS*.
- Q12. Below is our research team's working definition of *EVMS*. Do you agree with this *EVMS* definition?
- Q13. Since you answered *No on Q12*, please explain why you disagree by providing comments.
- Q14. Does your organization have another term that is used in place of the term *EVMS*?
- Q15. Since you answered *Yes on Q14*, please provide your organization's other term that is used in place of the term *EVMS*

EVMS Maturity Assessment

- Q16. Does your organization evaluate maturity of *EVMS* in addition to *EVMS* compliance?
- Q17. Since you answered that *EVMS maturity* is evaluated in your organization, **how** is maturity evaluated?
- Q18. Since you answered that *EVMS maturity* is evaluated in your organization, **who** typically conducts this evaluation?

EVMS Practices

- Q19. What are the most challenging aspects of managing a project/program using the *EVMS*. Please rank the **top three**, with one being the most challenging aspect.
- Q20. The following core processes typically make up an *EVM system*. In your opinion, please rank the **top three** in the list below in terms of their impact on *EVMS* effectiveness.
- Q21. The following factors can impact the environment of *EVM systems*. Based on your experience, please rank the **top 5** factors in order of importance.

EVMS Strategies & Comments

- Q22. Please provide key strategies that your organization uses to identify and mitigate *EVMS* deficiencies or take advantage of opportunities for improvement.
- Q23. Please feel free to share any other thoughts about *EVMS* assessment with the research team.

Figure 3.5 EVMS Survey Questions

3.5 Results of the Comprehensive Literature Review on EVMS

Library databases were used for searching, which included the following keywords: EVM, EVMS, maturity, environment, and EVMS assessment models. Earlier findings of the literature review were published by Cho et al. (2020) entitled, “EVMS Reliability: A Review of Existing EVMS Literature.” This study searched extensively for EVMS-focused studies from diverse sources, including the example sources shown in Table 3.1.

To obtain a sufficient and representative amount of literature, diverse types of references are included, such as journal papers, conference proceedings, institutional compliance documents, dissertations, books, and research reports. In addition to published literature, the study also reviews documentation from U.S. government agencies and includes published EVMS standards and guidelines.

Table 3.1 Sample of EVMS Literature Review Sources

	Review Sources	**Publisher**
1	AACE International Transactions	AACE International
2	The Measurable News	College of Performance Management
3	Earned Value Management Library	Project Management Institute
4	International Journal of Emerging Engineering Research and Technology	-
5	International Journal of Project Management	Elsevier
6	Procedia - Social and Behavioral Sciences	Elsevier
7	CII Knowledge Base	Construction Industry Institute (CII)
8	Journal of Management in Engineering	ASCE
9	Journal of Construction Engineering and Management	ASCE
10	Journal of Computing in Civil Engineering	ASCE

A total of 395 documents were identified and collected. For further analysis, those studies were first categorized in eight categories, based on the objective of the document:

(1) EVMS guidelines and global standards, (2) EVMS definitions and best practices, (3) EVMS historical review papers, (4) EVMS forecasting/prediction and reporting, (5) Application of risk management in EVMS, (6) Application of EVMS to specific cases, (7) EVMS environment factors, and (8) Maturity models in different application areas. Table 3.2 shows the number of identified sources in each category. The EVMS guidelines and global standards category includes a total of 44 research papers and 33 guidelines and government standards. Those documents focus on providing guidelines to implement the system for their organizations or improve the efficiency and effective application of the system. Due to diverse organizations applying EVMS internationally, many guidelines were developed, tailored to specific organizations. The EVMS forecasting/prediction and reporting category includes 93 papers, which is the second-largest category in this analysis. With technological improvements and advanced statistical analysis methods, EVMS is able to improve performance prediction.

The literature review clearly shows that many practitioners and researchers consider EVMS as a management tool to support timely decision-making for projects and programs. Categories (1) and (2) consider the proper utilization of the EVMS to implement and execute projects/programs and the tailoring to the unique organizations. Category (3) shows that research on EVMS started in 1962. Still, many researchers claim that some EVMS applications are not reliable and have a gap in implementation (Orgut et al. 2020). Research projects identified in category (4) addressed this issue and provided a more accurate estimation from the system by applying diverse statistical analysis. In addition, category (5) presents that more people are focusing on how to improve the tool application on their decision-making process by providing risk analysis. Category (6) not only identified that people are using EVMS for their unique project management, but it also applied diverse technologies to bring real-time data. Even though most researchers are focused on improving forecasting, this study identified that many other researchers in category (7) suggest a better EVMS implementation and execution environment that supports appropriate development and corrective actions. This study also suggests developing a maturity model, which is also applied in other industry areas (category (8)) such as information technology (IT), to assess and improve EVMS reliability.

Table 3.2 Identified EVMS Literature Categories and Number of Sources

	Category	**# of Identified literature**
1	EVMS guidelines and global standards	44 research papers 33 guidelines and government standards
2	EVMS definitions and best practices	45 papers
3	EVMS historical review papers	34 review studies
4	EVMS forecasting/prediction and reporting	93 papers
5	Application of risk management in EVMS	35 papers
6	Application of EVMS to various cases	64 papers
7	EVMS environment factors	30 papers
8	Maturity models in different application areas	17 papers

The literature was then categorized according to the ten EVMS maturity processes shown earlier in Figure 3.3. Only papers published after year 2000 are counted, and historical papers, guidelines, and standards were excluded from this first analysis because guidelines are typically include most, if not all, processes for a given organization and are usually updated over time, which defeats the purpose of this first analysis. Findings for the ten processes, in terms of the number of documents found that address each EVMS process, are shown in Figure 3.6. All included literature with categorization is presented on

APPENDIX G. The following Appendix presents 294 references used in the EVMS maturity and environment analysis. The table links each reference to the below EVMS processes and environment categories. Note that some papers cover more than one process, so the numbers shown may be greater than the actual total number of papers. The papers are sorted to each process based on their keyword. For example, if the paper contains the keyword, such as the critical path method (CPM) and scheduling, it is allocated to the planning and scheduling process. Moreover, if the paper contains multiple keywords from diverse processes, they are located on multiple processes.

The graph clearly shows the focus areas of EVMS research over the past two decades. Many papers have investigated the "analysis and management reporting" process. The "indirect budget and cost management" process also includes PMB establishment and analysis; therefore, the data indicate that the majority researchers are focusing on the data analysis aspects of EVMS. The third largest category is "planning and scheduling", which is the process to establish a reliable PMB, and "risk management" is the fourth ranked process in this analysis. These results show that research on EVMS is mostly on the technical side of EVMS, while other EVMS processes are not studied to the same extent.

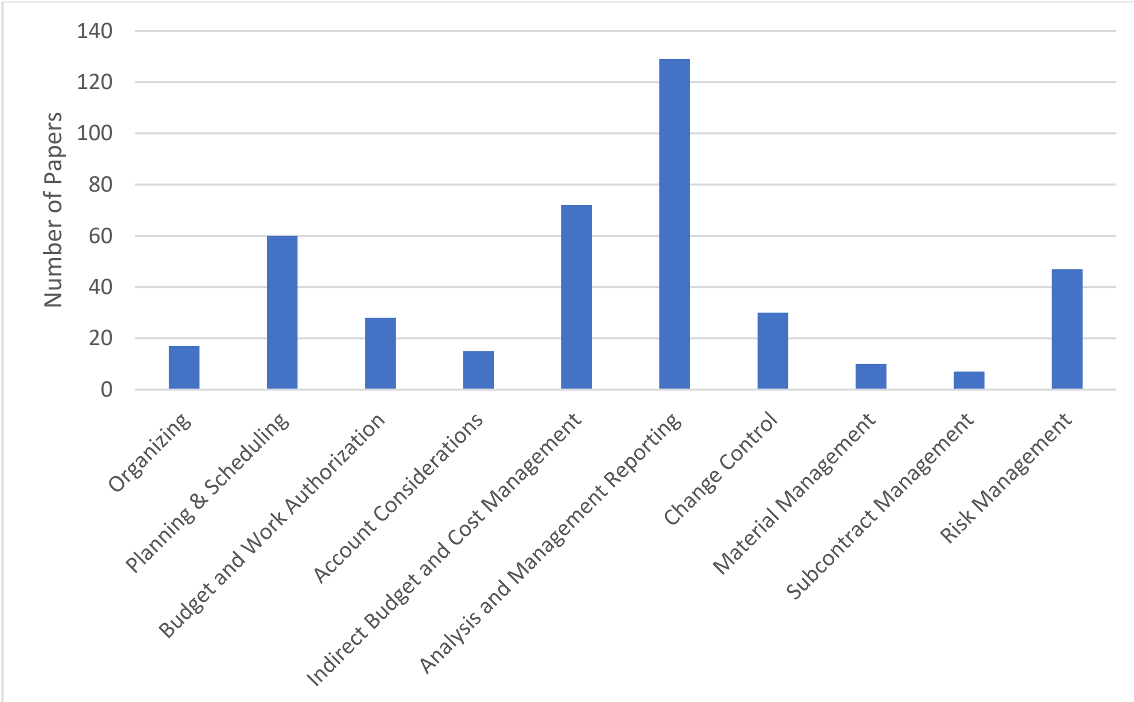


Figure 3.6 EVMS Literature Review by Processes

Then the literature was categorized according to its publication timeline. Figure 3.7 shows that EVMS-related research significantly increased after year 2010, and "analysis and management reporting" maintained its lead as the most prevalent researched process. The preliminary objective of EVMS utilization is integrating scope, schedule, and cost from real-time data and technology improvements such as building information modeling (BIM). This objective booster its research on analysis and reporting side. The risk management related research also increased based on reliable analysis. Except for analysis and management reporting, research on all other processes is reduced after 2015. This trend indicates that EVMS users still have a desire to estimate project progress accurately. Moreover, the previous research until 2015 more focuses on the accuracy of prediction, but current research transferred its trend to use the analysis on risk management.

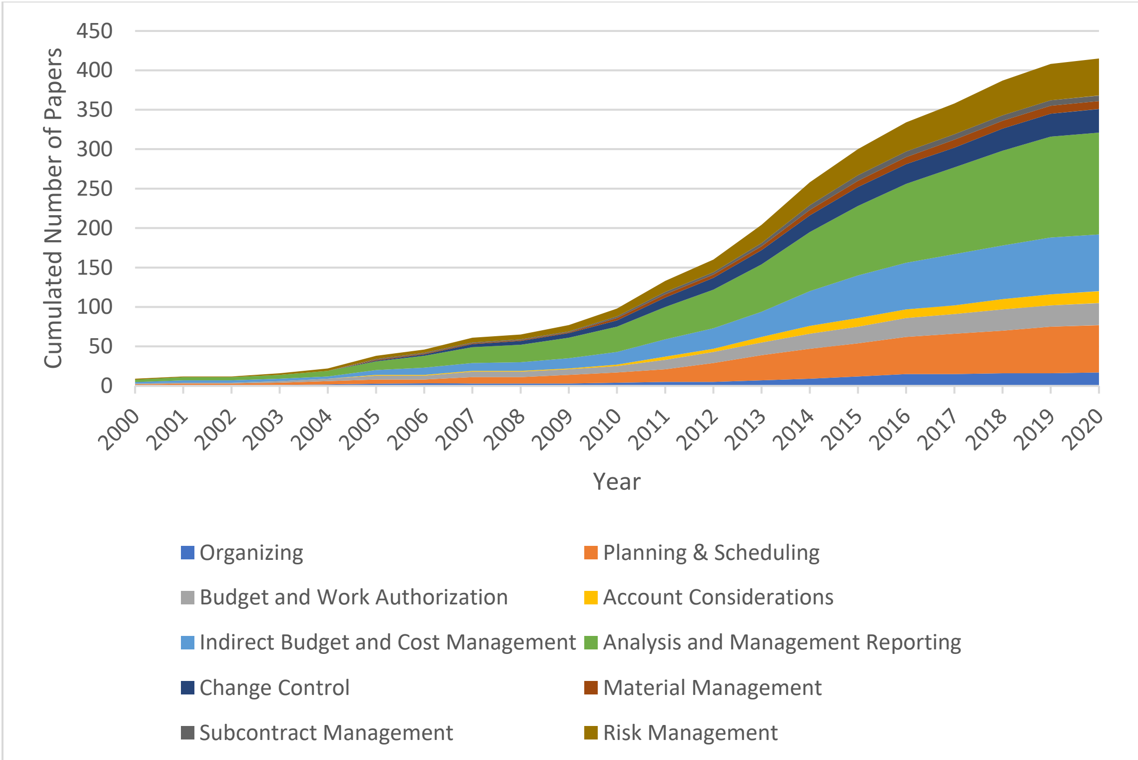
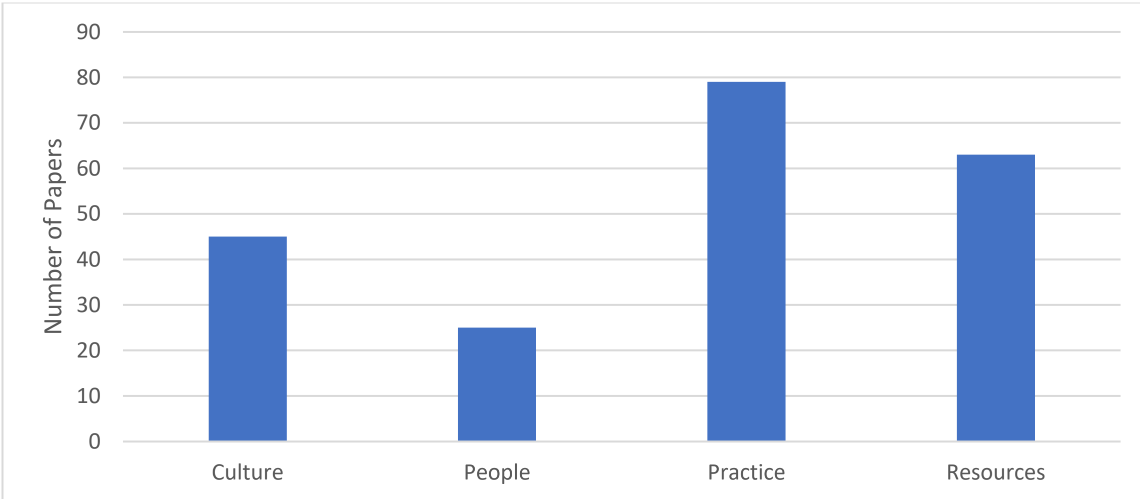
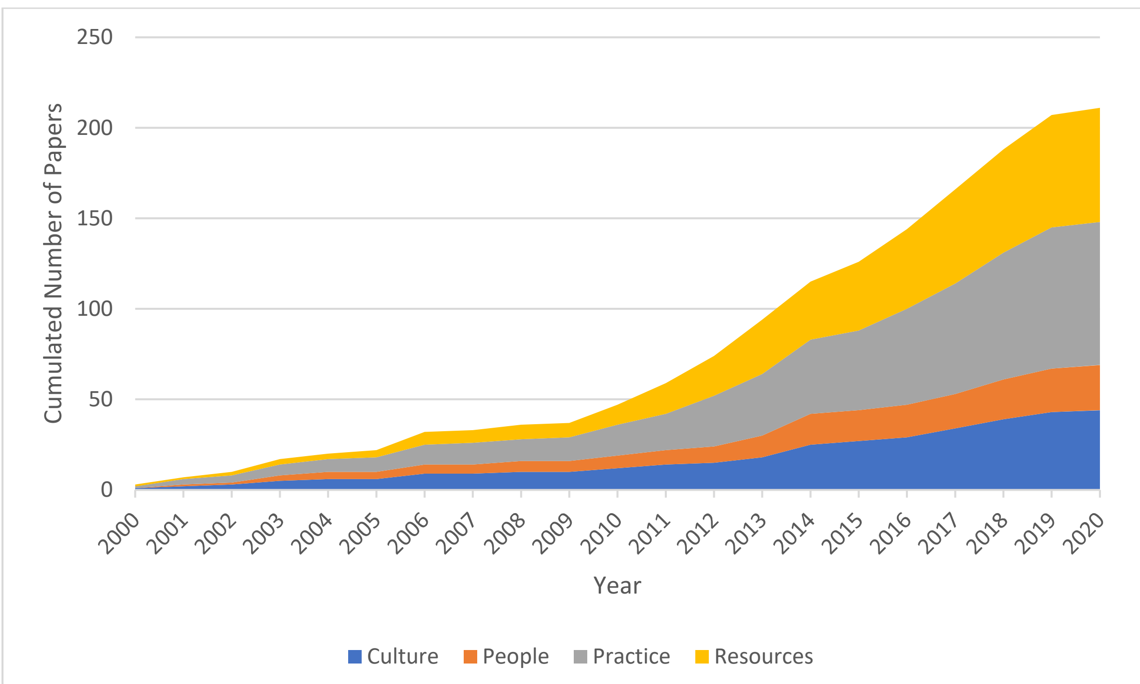


Figure 3.7 EVMS Literature Trend by Processes

The second category is the EVMS environment, which referred to culture, people, practice, and resources. Without considering the EVMS implementation and execution environment, reliable EVMS operation cannot be guaranteed. Figure 3.8 shows the number of EVMS environment-related research. The graph shows that EVMS related research is more focused on the practice and resource side, including standard process/practice, data, integrated system, and implementation resources. In addition, the trend of the research presents that the importance of the EVMS environment increased year by year. This indicates that the appropriate operation of EVMS is becoming a critical issue.



(a) The Number of Papers by Environment Category



(b) The Trend of Papers by Environment Category

Figure 3.8 EVMS Literature Review by Environment Categories

After a review of the diverse studies conducted on EVMS, the author found a gap in addressing the reliability of EVMS. Most studies focus on the technical side of EVMS that increases the predictability of the project outcomes and performance progress;

however, there is a need to understand whether the tools, the environment, or the factors around EVMS could help create a reliable system. General guidelines exist but can be interpreted in different ways; the author did not find a holistic approach that ensures all key elements, tangible and non-tangible, exist, are sufficiently developed, and are effective, making it a reliable EVMS. Another gap found is that previous studies mainly focused on general contractors. The role of the government or owner in the development, assessment, and application of EVMS was not consistently documented. The topic of this chapter links the existing studies in the third literature category (Improving EVMS reliability) to today's industrial practices in order to analyze and assess the reliability of EVMS taking into account factors or elements that affect EVMS by both Contractor and Government/Owner.

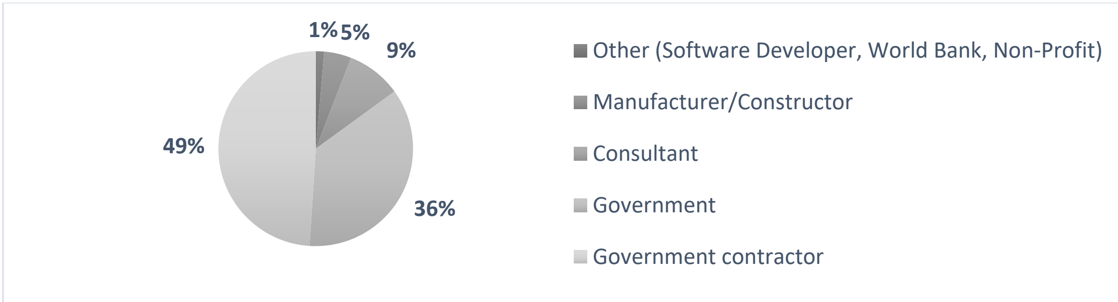
The literature review revealed a large body of knowledge on EVMS, covering topics such as forecasting, predictability, practices, and guidelines, and it is aligned with Cho et al. (2020)'s study. However, gaps exist in the literature with respect to EVMS maturity and environment. First, there is a gap in methods to assess EVMS maturity. Even though there are many research projects performed on EVMS processes, there is no clear assessment tool or method to inspect core problems. Second, although EVMS environment factors are widely discussed, and more research has been performed recently, there is no comprehensive listing of key factors or an assessment method to gauge EVMS environment factors. The literature review was critical to identify these gaps, develop common terminology and definitions, and design the industry survey.

3.6 Current Practice of EVMS

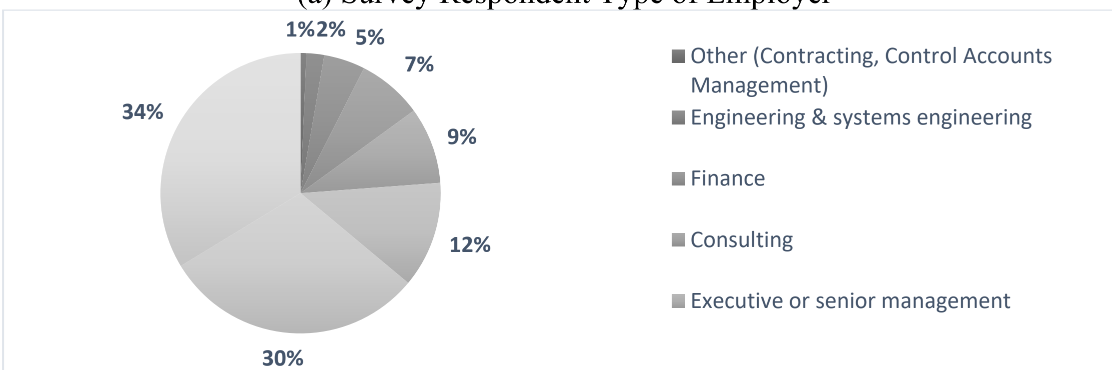
3.6.1 Demographics

Each of the 27 research team members was asked to distribute the survey to their colleagues involved in EVMS. The survey was distributed through the following channels: NDIA, Energy Facility Contractors Group (EFCOG), DOE Project Management (PM) workshop, Project Management Institute (PMI), U.S. Government Accountability Office (GAO), Office of Management and Budget (OMB), and team member's internal organizations. A total of 294 usable responses were returned. Figure 3.9 provides the breakdown of the respondents' demographics in terms of organization type, employment role and the years of career experience.

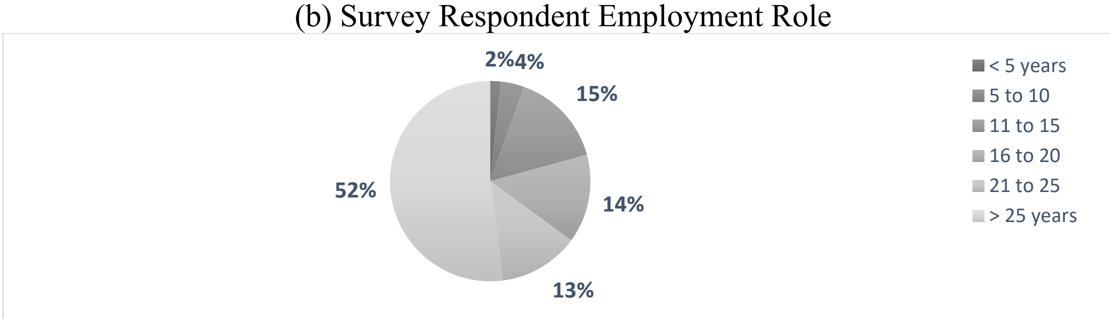
Figure 3.9 presents the demographical characteristics of survey participants. From 294 answers, Figure 3.9 (a) shows about half of the answers from a government contractor and one over third as government officers. In addition, about 10 percent of participants are consultants, 5 percent manufacturer or constructor, and a few others from software developers, world bank, and non-profit organizations. The ratio between government and government contractor indicates that the survey collects sufficient data from both government and contractor side. Figure 3.9 (b) presents the participants' employment roles. Major participants' role is project control management and project/program management. Executive or senior management also has about ten percent of the answers. Lastly, about half of the answers are from the experts who have above 25-year experience in EVMS related fields and two percent of respondents have less than five year experience (Figure 3.9 (c)). The respondents had an average industry experience of 20.8 years, calculated by summing the products of the career experience range' average and number of respondents.



(a) Survey Respondent Type of Employer



(b) Survey Respondent Employment Role



(c) Survey Respondent Years of Career Experience

Figure 3.9 Survey Demographics Result

3.6.2 EVM and EVMS Definitions

The set of survey questions 4 to 15 were on definitions. The respondents were first asked whether their organizations have the standard, organization-specific, definitions for EVM and EVMS (questions 4 and 10). Next, questions 6 and 12 asked respondents whether they agreed with the research team's working definitions of EVM and EVMS. The results of these questions are shown in Table 3.3.

As shown, 82 percent of respondents indicated that their organizations have a standard internal definition for EVM. This number was 221 (77 percent) for EVMS. Since the survey was anonymous, further observation with respect to organizations could not be extracted. However, this analysis implies that the majority of the respondents are aware of their organization's standard definitions. The respondents whose organizations had standard definitions for EVM and EVMS also provided them in the survey (questions 5 and 11). These definitions differed from one organization to another, but there was a commonality among certain terms and ideas. As also shown, on average, 20 percent of the respondents reported that their organizations did not have standard definitions for either EVM or EVMS or both. This lack of definitions may cause misunderstanding, failure to meet expectations, and difficulty in the application of EVMS among stakeholders. Having standard, consensus definitions should allow communication to start from a common point, support alignment in understanding, unification of perceptions, and potentially obtaining the full benefits of the practice. Finally, as indicated, 242 respondents (82 percent) agreed with the provided definition for EVM. Moreover, 242 respondents (85 percent) also indicated agreement with the definition of EVMS. Hence, a large majority of the respondents agreed with both working definitions. The author and research team feel that the working definitions can be considered valid with minor changes needed for improvement.

Table 3.3 Respondents' Results on Definitions

	Respondents' Organizations Having Standard Definitions		**Respondents' Agreeing with Working Definitions**	
	EVM	**EVMS**	**EVM**	**EVMS**
Total	294	287	294	285
Yes (%)	82%	77%	82%	85%
No (%)	18%	23%	18%	15%

Respondents who did not agree with the provided definitions were asked to provide reasons why they disagreed and how the definition could be improved (questions 7 and 13). The feedback received on both definitions were reviewed and analyzed. First, Table 3.4 represents top feedback from the 52 respondents who did not agree with the provided EVM definition and its frequency (question 7).

Table 3.4 Respondents' Feedback on Working Definition

Category	**Feedback**	**Frequency**
EVM	The definition should address measuring of status and progress against a plan.	9
	Forecasting aspect is missing from the definition.	8
	Rethink use of word "control" in the definition.	5
	Risk component should be included in the definition.	4
	EVM is a tool, but it is not the only tool as implied in the definition.	4
EVMS	Missing notion of integration with other systems or processes in the definition.	11
	The definition should include reference to EIA-748 32 guidelines or other standards.	7
	Decision-making aspect is missing from the definition.	4
	The definition should indicate that EVMS is a tool to measure performance as well.	4
	The word "objective" or to "objectively" measure performance is missing in the definition.	4
	Phrase "associated work scopes" is not clear.	4
	Notion of risk management or risk is missing from the definition.	4

3.6.3 EVMS Maturity Assessment Practice

Measuring the maturity of systems is essential to obtain the expected result. To determine the current practice of maturity assessment, the survey question was developed: "Does your organization evaluate the maturity of EVMS in addition to EVMS compliance? For example, do you have a document that provides specific criteria for giving a 1, 2, 3, 4, or 5 score (on a Likert scale) for the NDIA EIA 748-D's 32 guidelines, or other similar assessment mechanisms?" Based on 280 answers, 28 percent of respondents answers they have a maturity assessment process. The next question for who responses have maturity assessment, an additional question was asked: Since you answered that EVMS maturity is evaluated in your organization, how is maturity evaluated? Check all that apply. The answer shows that 70 percent of people have an internal organizational proprietary maturity model and 30 percent of people get maturity assessment through consulting organizations.

The respondents who reported that their organizations evaluate maturity were asked about the party or entity which typically conducts the evaluation (question 18). One or more choices could be answered. The results are shown in Table 3.5. Those who do evaluate maturity mostly rely on subject matter experts, and some of the respondents mentioned third-party review, contractors, and client. Since maturity assessment is not exactly aligned to self-governance, the result of Table 3.5 shows most of the respondents are confused with maturity assessment and self-governance. Self-governance us a repeatable process in which the contractor and owner of the EVMS oversee itself and controls its own affairs (Humphreys Associates 2019). However, this result clearly shows that there should be a clear maturity assessment method that can support EVMS review, including self-governance.

Table 3.5 Evaluator of EVMS Maturity as Reported by Survey Respondents

Entity who Conducts Maturity Evaluation:	Percent	Frequency
The EVMS subject matter expert or organization's EVMS office	42%	67
Third party peer review	15%	23
By the contractor	13%	21
By the client/customer	13%	20
Consulting review	9%	15
By the owner	8%	12
Total	**100%**	**158**

3.6.4 EVMS Application Challenges

There is no doubt that EVMS significantly improves project/program management practices. However, many EVMS experts complain about some obstacles to apply them appropriately. To identify this obstacles and challenges, the survey question was developed. During the survey, the following question was asked, "What are the most challenging aspects of managing a project/program using the Earned Value Management System (EVMS). Please rank the top three, with one being the most challenging aspect. (#1 is the most challenging)." Figure 3.10 shows the result of the survey result from 278 answers.

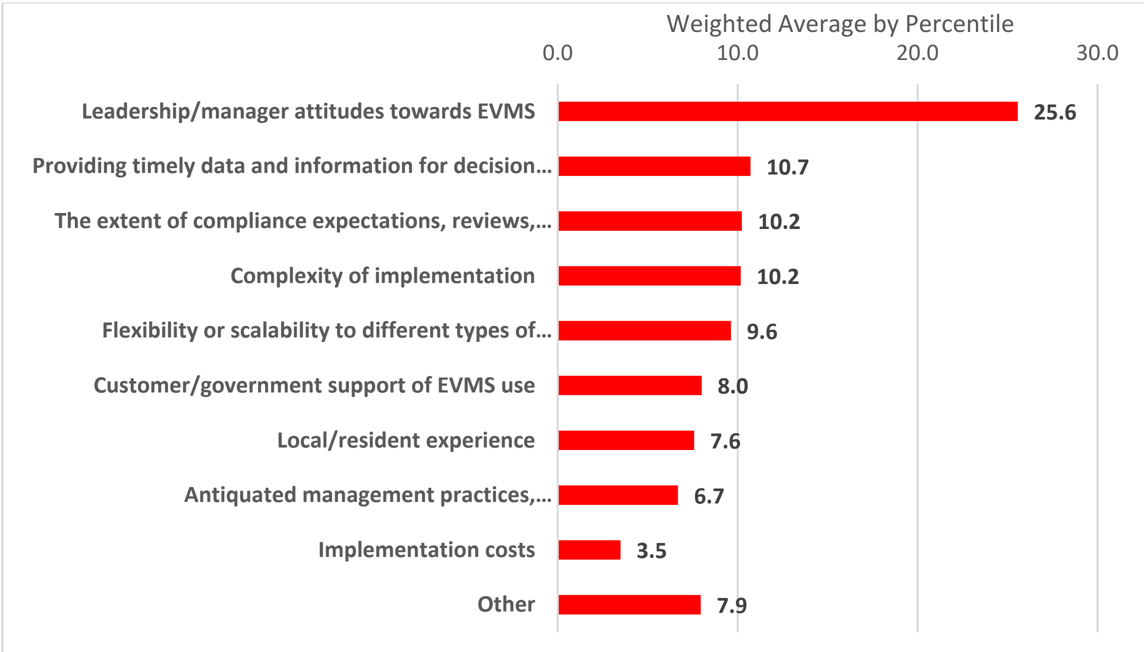


Figure 3.10 Top Challenging Aspects of Managing a Project/Program Using EVMS (n=277)

The biggest challenge to using EVMS is identified as leadership/manager's attitudes towards EVMS. Since EVMS is applied as a decision-making tool during project execution, appropriate involvement of leadership is critical. EVMS should allow timely data and information for decision making because the data keep changes and updated while executing the data. The late update may have a significant negative impact on the project. EVMS compliance expectations, reviews, and oversight are selected as the third challenge. While methods are in place to assess compliance of the EVMS to the accepted standards of the Electronic Industries Alliance (EIA)-748, these methods are often based on an agency's preferred interpretation. For years, government and industry have debated the finer points of EVMS compliance with no real consensus or resolution.

The complexity of implementation is also identified as a challenge. EIA-748 guidelines are linked with EVMS implementation and execution. Thirty-two guidelines are associated with each of the processes, and they are inter-related with each other.

Flexibility and scalability to different types of organizations and projects are also identified as an important challenge. The EVMS is required for some Federal Acquisition Regulation (FAR) based contracts. The OMB in Circular A-11, Part 7, Capital Programming Guide, requires federal departments to implement the EVMS on major capital acquisitions requiring special management attention because of their importance to the department's mission. However, organizations have a different interpretation of the guidelines and unique management practices, so the system should be tailored to match their expectations. Many of these organizations have support on EVMS and without their support, it is challenged to apply the system to the project.

The challenges to applying EVMS supports the literature review that it is important to consider environments. The "other" challenges identified from freeform input support it. Contractual limitation, agile application environment, improper application about EVMS tool are stated by EVMS survey participants. All of these issues are considering the management issues for EVMS operation. Some others mentioned the challenges as integration challenge, change scope and control, and project/program requirements and size. All of these issues can be considered in the maturity assessment for the considerations.

3.6.5 EVMS Application Processes

Ten processes are identified for the implementation and execution of the EVMS for project/program management. To identify the importance of the maturity assessment based on the process, the following question was asked for survey participants: "The following core processes typically make up an EVM system. In your opinion, please rank the top three in the list below in terms of their impact on EVMS effectiveness. (#1 is the highest impact.)."

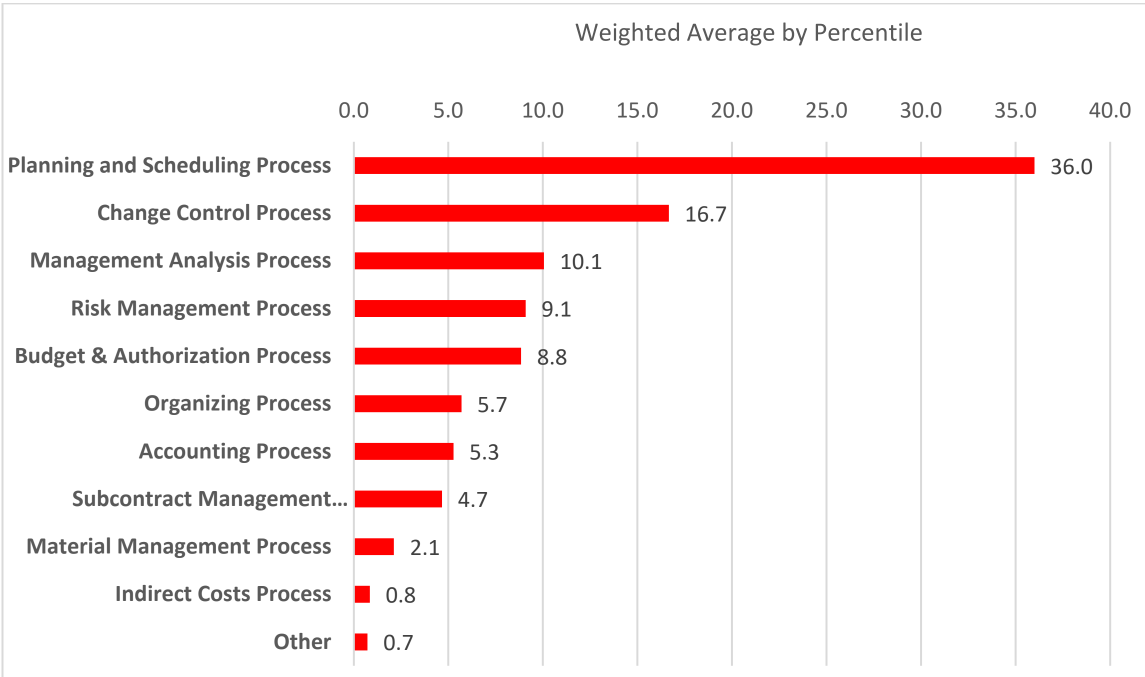


Figure 3.11 Top EVMS Processes with the Highest Impact on EVMS Effectiveness (n=275)

The planning and scheduling process is chosen as a top process that impacts on EVMS effectiveness. This clearly presents that EVMS users expect to use the tool preliminary as a planning and scheduling control system. The following process is a change control process to manage change orders during utilization. A clear process to manage and track change orders is essential for reliable EVMS because the project changed and updated continuously. The management Analysis process is selected as a third important process. EVMS provides estimations throughout the data and provides cost and schedule variations for analysis. The fourth important process is identified as risk management. Based on the analysis result, proper risk management should be performed. The budget and authorization process is identified as the next important process, which indicates that the EVMS is integrated management functions. The organizing process is critical for scope identification. The accounting process is supporting analysis and risk management by organizing control accounts that is a manageable level. The subcontract management process is often ignored because of the system used by the general contractor and customer's communication tool. However, without subcontract management function, scheduling and risk management cannot be performed properly. The material management process is identified as a less important process, but it impacts the price difference for the entire project. This price difference should not be counted on the variance analysis, but the price should be updated to the system to identify the final price. Lastly, the indirect cost process is indicated as the least important process. Other processes indicate forecasting, scoping, and EVM data collection, but all of them can be aligned to identified ten processes, such as forecasting is equivalent to the management analysis process, scoping for organizing process, and EVM data collection for planning and scheduling process.

3.6.6 EVMS Environment Elements

This study identified four main areas that are tailored to the EVMS environment: (1) Culture, (2) People, (3) Practices, and (4) Resources. To determine the importance of the environment factors, one survey question was organized: "The following factors can impact the environment of Earned Value Management (EVM) systems. Based on your experience, please rank the top 5 factors in order of importance (#1 is the most important)."

Factors in the question, which are presented in Table 3.6, were originally developed from PDRI MATRS Accuracy factors, which have top 18 high weights, and tailored to EVMS practices. To collect any other opinions from experts, this question contains two other text inputs.

Table 3.6 List of Factors Included in the Question for EVMS Environment

Number	Factors
1	Leadership team's previous **experience planning, designing and executing** an EVMS on a project/program of similar size, scope, and/or location
2	**EVMS Stakeholders** are appropriately represented on the project leadership team
3	Project/Program **leadership** is defined, effective, and accountable
4	**Organizational culture** fosters trust, honesty, and shared values
5	**Technical capability and relevant training/certification** of EVMS implementation team
6	**EVMS implementation team experience** with the local regulations, with similar projects
7	**Internal controls team** is independent of the program and has the authority to affect change
8	**Stakeholders** are appropriately represented on the EVMS implementation team (e.g., contractor, operations and maintenance, key design leads, project manager, sponsor) and have a clear understanding of the project scope
9	**Communication** within the EVMS implementation team is open and effective; a communication plan with stakeholders is identified
10	The organization implements and follows a standard EVMS Development process, has a **formal structure** or process to prepare EVMS, and implements **planning tools** that are used effectively
11	**Priorities** among EVMS requirements are clear
12	**Commitment** of key EVMS personnel
13	**Calendar time** allowed for preparing EVMS and **management tools** available including technology/software
14	**Local knowledge** (e.g., institutional memory, understanding of laws and regulations, understanding of site history)
15	**Quality** and level of data available
16	**Sufficient investment** to implement EVMS
17	**Availability of standards and procedures** (e.g., local EVMS requirements, standard operating procedures, and guidelines)
18	**Sufficient EVMS requirements definition and agreement** among key stakeholders and sponsor(s)
19	Other:
20	Other:

Figure 3.12 shows the top eight factors that affect the EVMS environment. Organizational cultures are chosen as the top factor, which indicates that stakeholders around the system affect significant rather than the preparation of the system. Standard EVMS practice is selected as an equally important factor for EVMS implementation. The third and fourth factors are the leadership team's experience and leadership's role to utilize EVMS because it should be work as a decision support tool from the top. The reliable and quality data is the following, which indicates that without the correct data, no appropriate decision can be made through the system. Technical capability, relevant training/ certification, and EVMS team's experience are followed that indicates EVMS implementation and execution team's ability should be following leadership.

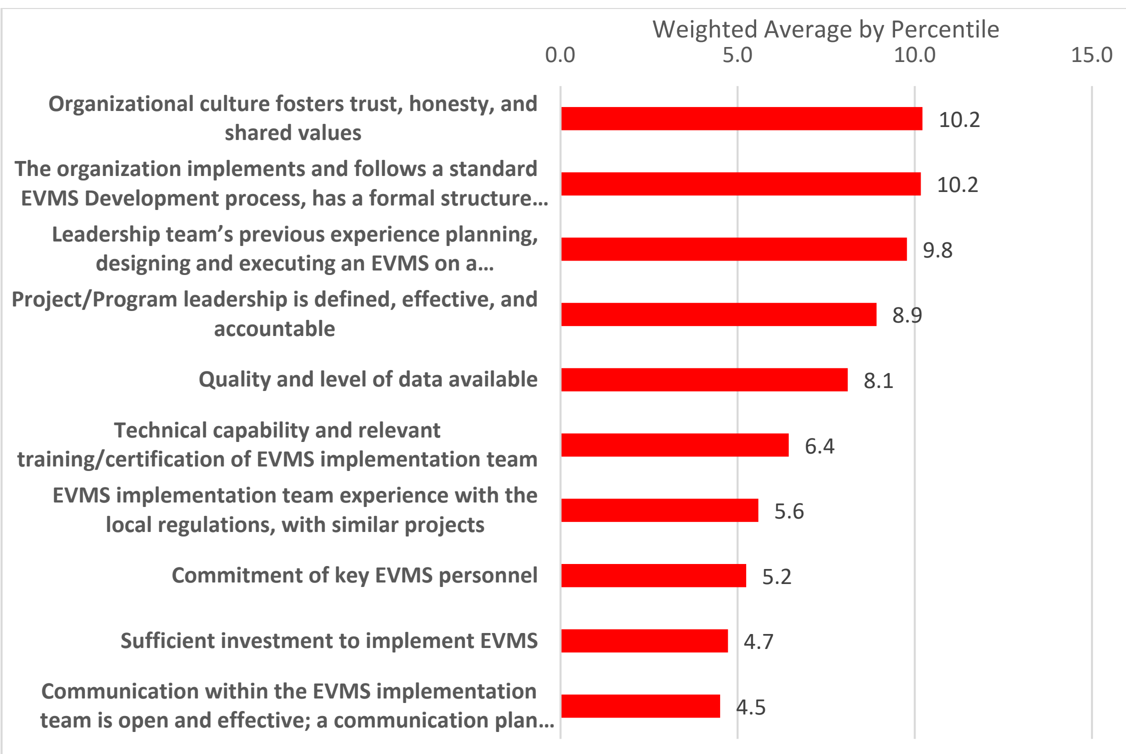


Figure 3.12 Top Factors That Can Impact the EVMS Environment (n=272)

The survey collects freeform inputs from experts to identify any new EVMS environment-related information. Many of the collected answers can be distributed to the existing factors. For example, one of the answers mentioned “management ability to accept real data versus misinterpreting performance,” which can be aligned “15, quality and level of data available” and “5 Technical capability and relevant training/certification of EVMS implementation team.” After cleaning the answers, the following list of answers is collected and presented in Table 3.7.

Comments provide a good list of discussion points. Ownership’s support is important, including leadership and lower management level. EVMS users are looking for convenience over compliance, which can be included in the maturity assessment rather than the environment. Oversight should be considered for appropriate utilization. New technology can be linked with the system, such as Building Information Modeling (BIM). Not only the data quality, which generated through EVMS, scheduling, and planning quality is important to make a reliable system. This issue can be linked with the previous effort from PDRI studies. Stakeholder’s active participation is also stated as one of the potential factors. Lastly, one comment states that EVMS should be a reporting or contract management tool, rather than a management tool. However, the other survey participant mentioned using the data from EVMS for management reviews. This argues may come from the organizational system boundary, such as EVMS is one of the subsets of enterprise resource planning (ERP), and it integrates multiple functions in the ERP system. A clear boundary of the system can help this issue.

Table 3.7 Other Factors from Survey Comments

Number	Other Factors from Survey Comments
1	Ownership and support of processes and procedures
	Client requirements and support of EVMS
2	Convenience over compliance
3	Poor oversight
4	New technology
5	Quality of scheduling & planning
6	Participation and encouragement
7	Treating it only as a reporting tool or as contract management rather than a management tool
8	Use of data in management reviews

3.7 Research Impact

This study analyzed literature articles that published and performed a survey from the EVMS experts to develop an EVMS METR in the future. Therefore, the impact of this study is majorly supporting this new tool development. When the tool is developed, it will be applied to the U.S. government project/program in a diverse industry. Department of Energy (DOE) requests to apply EVMS for the project if the project cost is above $50M and the executive agent for compliance determination if the project value is more than $100M. Similarly, the Department of Defense (DoD) request to implement EVMS when the contract value is above $20M and at least 18 months period of performance. It also requests compliance determination if the contract value is over $100M. The result of this study is not available to transfer to monetary value, but this study provides some considerations to manage those big project/program management issues.

3.8 Conclusion

This chapter reviews the existing literature around EVMS reliability, including EVMS maturity and environment. In addition, this study performed an industry survey to capture the challenges and practices of EVMS implementation and execution. The literature review finds that many research projects are performed in terms of analysis and reporting process, and still, its trend is increased. However, the survey shows that industry practitioners consider the planning and scheduling process as a top process and analysis process as the third one. The research found that assessing the environment in which the EVMS is being implemented may also lead to a more reliable EVMS. More studies are more focusing on the EVMS environment, which represents culture, people, practices, and resources that support EVMS implementation and execution. The trend to study on EVMS environment is kept increasing. The industry practitioners' response to challenges confirms that most important factors as environment-related issues, such as leadership and reliable data. A mature EVMS in the right environment may prove to be more reliable. Ongoing work will continue to add more documents to this analysis of literature, and then future research will use the findings of this chapter and consider both maturity and environment assessment factors to build a comprehensive EVMS rating index that can be used jointly by Government/Owner and Contractor to improve alignment and project success.

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4. USE OF PAVEMENT PERFORMANCE DATA: DESIGN, CONSTRUCTION, AND OPERATION AND MAINTENANCE

4.1 Abstract

The use of alternative project delivery methods has grown significantly over the last two decades. One such method is design-build (DB), which has been increasingly used due to its improved project cost and schedule performance. However, the project itself is only a fraction of the lifecycle of a built facility. Therefore, there is a need to understand whether delivery methods also impact the long-term performance of facilities. This chapter focuses on quantifying the long-term performance impact of DB on pavements, compared to pavements delivered using the traditional design-bid-build (DBB) method. The international roughness index is selected as the metric to compare ride quality across projects. In total, the author collected 9,946 data points representing 37 unique lane directions from 26 projects in six states, which they analyzed using linear mixed-effects methods. Results show that long-term performance of asphalt concrete pavement resurfacing DB projects is superior to that of comparable DBB projects by an equivalent of eight years of pavement life. A life cycle cost analysis shows the estimated monetary impact of these findings on the National Highway System is around $100 billion over the next 45 years.

4.2 Introduction

Currently, the United States (U.S.) public sector expends substantial resources to maintain its infrastructure systems. Despite these expenditures, the 2017American Society of Civil Engineers (ASCE) Infrastructure Report Card grades the U.S. infrastructure as

“D+”, which means there are concerns about the risks of failure (ASCE 2017). Moreover, ASCE estimates an additional $4.59 trillion are needed to make the necessary improvements on the entire U.S. infrastructure system before 2025. However, there are funding gaps on the order of $2.06 trillion, about half of the required funds (ASCE 2017).

While this issue is pervasive in all infrastructure systems, it is particularly relevant in transportation systems. In fact, ASCE (2017) estimates that approximately $2 trillion will be needed to adequately improve U.S. transportation infrastructure; this equates to about half of the total infrastructure funding needed in the U.S. To overcome this issue, Departments of Transportation (DOTs) across the U.S. expend substantial efforts to increase the performance of their roadway networks. To achieve this goal, designing and then manufacturing long-lasting pavements is a crucial strategy as it ultimately reduces the future financial needs to repair and reconstruct the existing roads (Miller and Bellinger 2014).

Alternative project delivery methods are being increasingly considered by state DOTs to improve the efficiency of their project delivery. These methods allow for early contractor involvement in the design phase of the project; they include various arrangements such as construction manager/general contractor (CM/GC) and design-build (DB). DB, for instance, is now permitted and authorized across most states and is being increasingly adopted for transportation projects (Design-Build Institute of America; DBIA 2017). A meta-analysis on the most recent 20 years of research on DB has shown that DB significantly reduces the project delivery schedule and improves cost certainty (Sullivan et al. 2017). The paper also identified a major gap in the body of knowledge: there is a need to assess long-term performance of facilities delivered using different project delivery methods. Although DB is becoming more prevalent due to project performance improvements, very little research has been conducted to investigate relationships between DB and the long-term performance of constructed pavements (Abkarian et al. 2017; Cho et al. 2017; Sanboskani et al. 2018).

Hence, this chapter aims to analyze long-term performance differences between project delivery methods, specifically DB versus the traditional design-bid-build (DBB) method. International roughness index (IRI) is the chosen metric for assessing long-term performance because it is measured yearly and it captures the overall ride quality of a pavement, representing other pavement distresses and serviceability (Al-Omari and Darter 1994; Lin et al. 2003; Irfan et al. 2009).

4.3 Background and Literature Review

4.3.1 Project Delivery Methods

A project delivery method specifies the relationships between the different project stakeholders and their timing of engagement in the project (Konchar and Sanvido 1998; El Asmar et al. 2013). The traditional project delivery method, referred to as DBB, is frequently used for transportation projects. In DBB, design and construction are under two separate contracts, with construction only beginning after the design is fully completed. However, due to performance limitations of DBB on complex projects, various alternative project delivery methods have evolved to fit projects' and owners' needs (Construction Management Association of America; CMAA 2012). The most common alternative delivery methods in transportation are construction management/general contractor

(CM/GC) and DB (DBIA 2014), and their market share is rising significantly (Vashani et al. 2016; Tulacz 2015).

Figure 4.1 illustrates the three most common project delivery methods. In DBB and CM/GC, the designer and builder have two separate contracts, but in CM/GC the builder is engaged (and construction may start) before the design is complete. DB also overlaps the design and construction phases, and in DB only one contract exists between the agency and the design-builder who is responsible for both the design and the construction of the project. This chapter focuses on DB pavement projects.

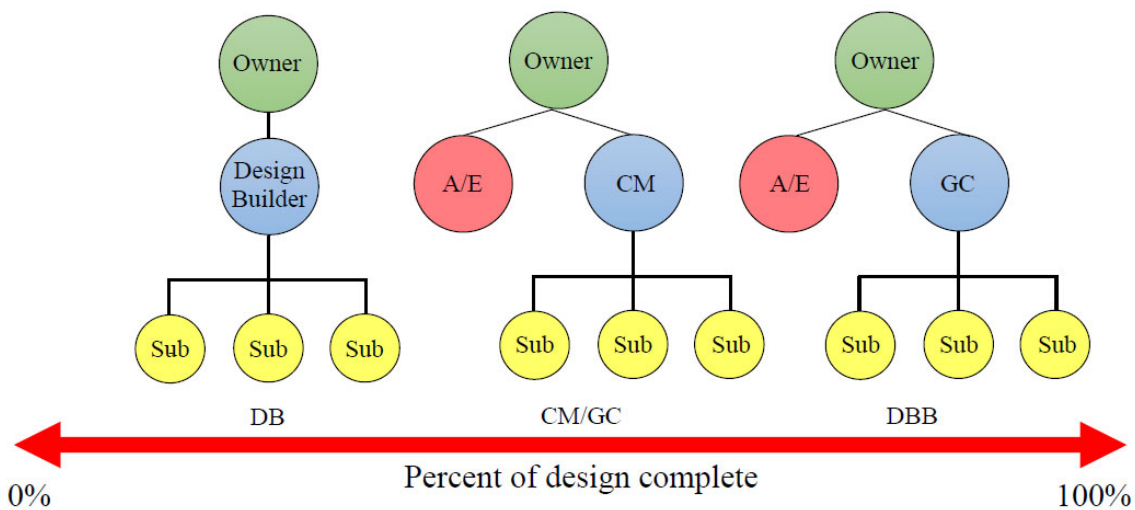


Figure 4.1 Delivery Systems' Contractual Relationships and Timing of Engagement (Adapted from El Asmar et al. 2013)

The DB adoption trend has grown recently with more states authorizing DB for transportation procurement. One of the reasons for this growth is research and practice showing DB's potential impact to improve project performance (Molenaar et al. 1999, 2009; Allen 2001; Parsons Brinckerhoff Quade & Douglas Inc. 2002; Fedeal Highway Administration; FHWA 2006; Touran et al. 2011; Shrestha et al. 2012; El Asmar et al.

2016). Most recently, Sullivan et al. (2017) performed a meta-analysis spanning two decades of DB performance literature and confirmed the improvements that DB offers with regards to schedule and cost certainty. The study also indicated the need to measure the quality of the built facilities accross the different project delivery methods by quantifying these long-term performance.

However, there has been no quantitative research performed to measure the relationship between delivery methods and the built facility's long-term performance. Gransberg and Shane (2010) investigated the relationship between project quality and project delivery methods. Their survey of owners and contractors shows that they expect CM/GC to have better performance than DBB on design quality outcomes. There is a wealth of literature on how DB impacts project cost and schedule performance, but there is a gap in understanding and quantifying its impact on the lifecycle performance of facilities, which the author address in this chapter.

4.3.2 International Roughness Index (IRI)

One of the early steps in this research included identifying a quantitative metric for long-term performance. The functional performance of a pavement is measured by the smoothness of the pavement surface. According to Fwa (2006), the most common measures of the ride quality are: present serviceability rating (PSR), present serviceability index (PSI), riding comfort index (RCI), ride number (RN), and the IRI.

Before the IRI was established, the disadvantages of previous pavement performance metrics were that those indexes rely on subjective human calibration (Lin et al. 2003), which causes inconsistencies in measurements throughout regions and projects.

Aiming to develop a better measurement of the smoothness performance index, the World Bank initiated the international road roughness experiment (IRRE) with ten different nations and established the IRI. The IRI is an independent profile-related index appropriate as an overall ride quality reference scale that can be computed from profilometric and vehicle response type measurement systems (Sayers et al. 1986). The World Bank and others have issued guidelines on the calibration and measurement of IRI (Gillespie et al. 1986). Now, IRI is most commonly used as an assessment tool for pavement smoothness (Kropáč and Múčka 2005). IRI is defined as accumulated suspension stroke (mm or in), in a reference passenger car, divided by the traveled distance (m or mile). It is a quantity calculted from a quarter-car suspension model, which uses the profile of the roadway as input. This profile can be measured in a number of different ways, but is most commonly determined using inertial profilers mounted to instrumented vehicles, which drive along the roadway at highway speed.

Figure 4.2 shows the expected trend of IRI based on the service life. When a road opens for service, IRI continually increases until maintenance or rehabilitation is performed (Irfan et al. 2009). Highway agencies often assign IRI thresholds to trigger maintenance and rehabilitation activities. These triggers are based on local experience and thus differ from state to state and by facility type (e.g., interstate, arterial). For example, in Maryland IRI below 60 in./mile implies very good condition, 60 to 95 in./mile is good, 95 to 170 in./mile is fair, 170 to 220 in./mile is mediocre and over 220 in./mile represents a pavement in poor condition (Arambula et al. 2011).

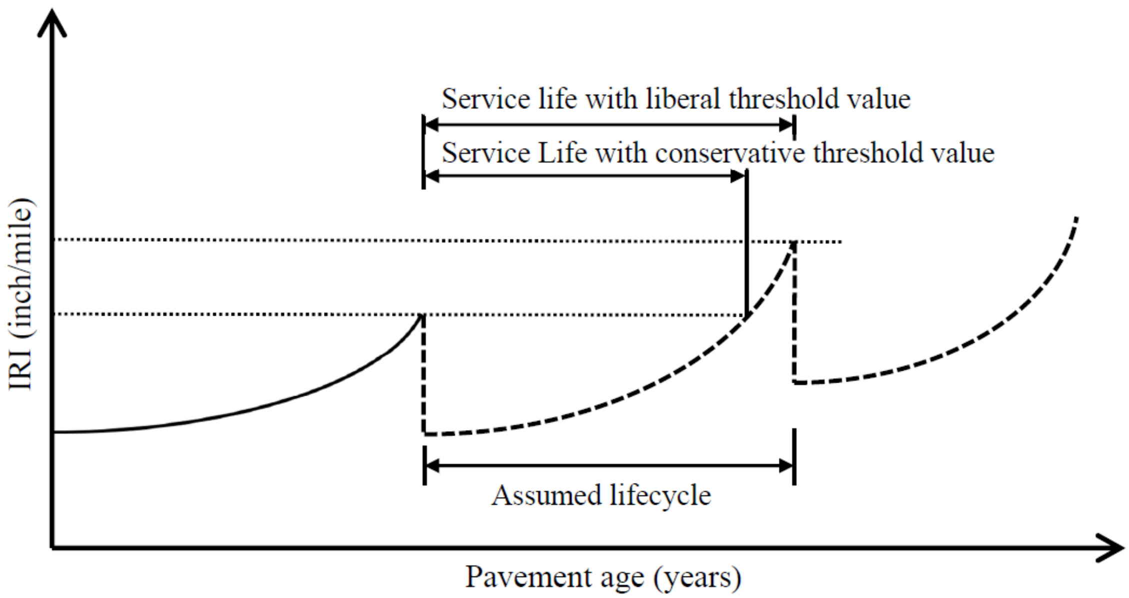


Figure 4.2 Explaining the Concept of Pavement Service Life Using IRI

This chapter uses IRI as the metric that gauges long-term performance since it allows for a consistent comparison between projects and across highway agencies. Moreover, IRI is measured yearly and captures the overall ride quality of pavements (Paterson 1990).

4.4 Research Methodology

This chapter's objective is to assess the impact of the DB project delivery method on the long-term performance of pavements. Figure 4.3 illustrates the research method. First, based on the literature review, IRI is adopted as the performance metric. The data is collected with very strict requirements to ensure valid comparisons between DBB and DB projects. In addition, data consistency is evaluated based on individual project information, such as the impact of construction and any existing measurement errors. Third, LME models are developed based on the modeling protocols presented in Pinheiro and Bates

(2000) and Zuur et al. (2009). Model interpretation and discussion constitute the fourth step. When the final model is selected, the parameters that correspond to fixed effects are evaluated as they convey important information with regard to the research objective. The last step of this research estimates monetary impacts of the findings. In this step, a life cycle cost analysis (LCCA) is performed using maintenance scenarios on DB and DBB projects.

Framework for Analyzing Long-term Performance of DB Pavement Projects

STEP 1 — **Literature Review and Identifying Variables**

- Literature review on DB and research methods
  - ✓ Pavement long-term performance variables
  - ✓ Identify IRI as the appropriate objective function

STEP 2 — **Data Collection**

- DB versus comparable DBB projects
  - ✓ Contact state DOTs to request DB projects
  - ✓ Find comparable projects delivered using traditional DBB
  - ✓ Check data consistency and comparability

STEP 3 — **Model Development**

- LME modeling to analyze longitudinal data

Objective Function	IRI			
Random Variable	Region	Project	Direction	
Fixed Variable	Deliv. met.	Pave. age	Pave. type	Proj. type

STEP 4 — **Result Interpretation**

- Model Interpretation
- Model Verification

STEP 5 — **Monetary Impact**

- Estimate the monetary impact using LCCA
  - ✓ Set a LCCA scenario based on the engineering advantages
  - ✓ Compute the impact of DB in terms of net-present value (NPV)
  - ✓ Predict monetary impact on the National Highway System

Figure 4.3 Research Method

4.4.1 Data Collection

IRI data for different projects were collected through direct contact with state DOTs. The data collection process can be summarized as follows:

A. Contact the state DOTs to request DB projects and IRI data for a preliminary analysis

B. Acquire projects delivered using DBB that are comparable to each selected DB project, and request information on these comparable DBB projects and their IRI data.

C. Check data consistency and comparability.

Twenty-seven different states were initially identified from the DB authorization map (DBIA 2015). Figure 4.4 shows the results of the data collection process. Data were collected and analyzed for six different states: Arizona (AZ), Colorado (CO), Michigan (MI), Minnesota (MN), Virginia (VA), and Washington (WA). Performance data from DB projects were also collected from Florida (FL), North Carolina (NC), and Utah (UT), but IRI data from comparable DBB projects could not be found. Thus, the data from these additional three states were not included in the analysis.

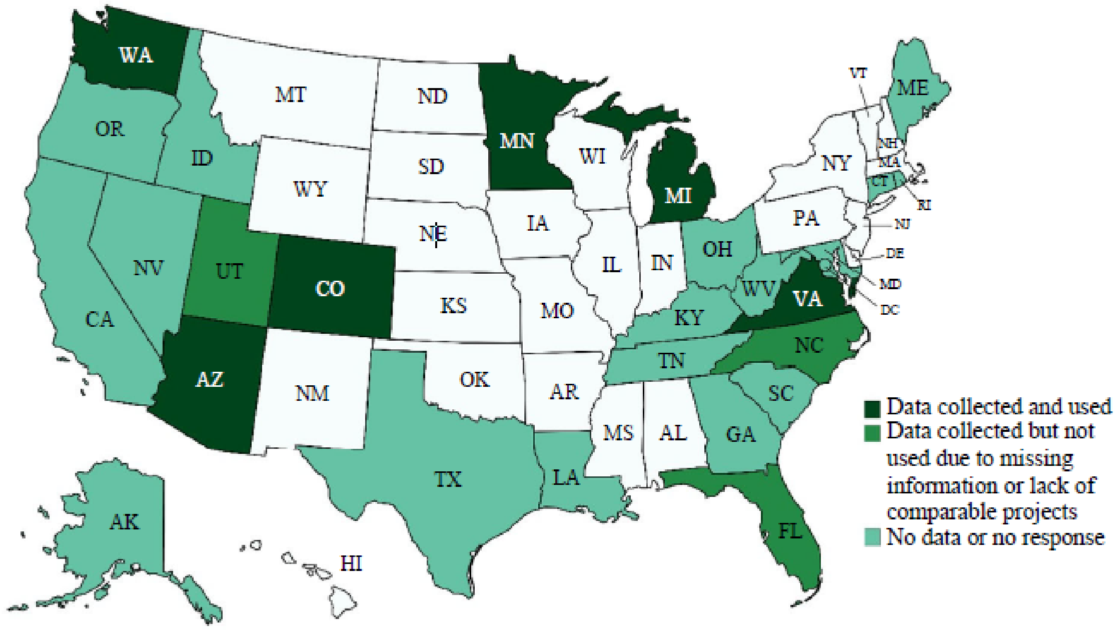


Figure 4.4 Geographical Distribution of Projects

4.4.2 Data Consistency and Comparability

Three key areas were focused on as part of the data collection process. First, IRI must reflect the effect of construction. For example, IRI is usually measured in regular driving lanes and thus when a DB project is used to construct or resurface a high-occupancy vehicle (HOV) lane, it will not be recorded in the ride-quality performance database. Therefore, detailed information with regard to each project's construction sections was assessed. IRI post-construction is expected to be significantly reduced relative to pre-construction; IRI values are also expected to increase as the pavement ages. This type of detailed data verification was completed for every project.

Second, a consistent measurement of IRI is important in order to accurately analyze long-term performance. As mentioned earlier, the IRI index increases with time (i.e., roads become rougher with age), but sometimes the measured IRI values decrease from year-to-year. This occurs because agencies may not always measure the same traffic lane each year. This assumption was also examined in every project in the database. In addition, the data is hard to measure the gap of the IRI value before construction and after construction because most of the IRI graph increased significantly at a certain point, including construction completion year. Therefore, this study compares the IRI value with the construction completion year and assumes that the road initiate to be operated when the IRI value drop-down significant at or after the construction completion year.

The third and most important area is finding comparable sets of data where the same basic type of construction was performed under the same conditions (e.g.; materials, traffic, climate, etc.) using both DBB and DB. The comparable projects were selected in a way to avoid changes in condition. For example, one project initially considered for this research had an "Open-graded asphalt rubber (AR)" overlay and others did not. AR affects IRI significantly (Venudharan et al. 2017). Since a comparable project was not found for this project, it could not be used in the analysis. Moreover, bridges and interchanges have different IRI profiles compared to general road sections so some agencies provide separate guidelines for measuring IRI for those sections (Henderson et al. 2016). In fact, McGhee (2002) suggested a new approach to measuring the ride quality of highway bridges due to these differentiations. Table 4.1 shows the data collection criteria that were followed consistently in order to reliably select comparative project sets.

Table 4.1 Acceptable versus Unacceptable Characteristics of Comparable Projects

Acceptable Project Characteristics of Comparable Projects	Unacceptable Project Characteristics
• Construction projects include the IRI monitored lane(s) • Available IRI data through the past 2-10 years (Ideally, accept the projects over 10 years if they have comparable projects) • Similar pavement structures • Similar ESALs/traffic volume • Similar climate • Similar soil conditions • Projects on the national highway system	• High-Occupancy Vehicle (HOV) lane(s) projects • Interchange projects • Bridge projects • Pavement preservation and minor Rehabilitation projects • Non-national highway system projects

After ensuring that all the remaining data was consistent and comparable, Table 4.2 shows a final list of the projects analyzed in this research. The 37 unique directional data sets from 26 projects come from six different states and the set number indicates comparable projects. This research considers two pavement types, namely asphalt concrete pavement (ACP) and Portland cement concrete pavement (PCCP), and two project types: resurfacing (ReSurf) and reconstruction (ReCon). Resurfacing projects repair surface defects of an existing pavement and in some cases localized structural failures, and install 1 to 3 inches of asphalt on top. Reconstruction projects remove the original pavement, sometimes including the aggregate base, and re-construct a new pavement structure (Fwa 2006). PCCP pavement data collected in this research only contain reconstruction projects, hence ACP results may be more representative.

Projects vary in length from 0.3 to 11.7 miles with different directions (e.g.; north versus south; east versus west). Moreover, in some projects, IRI is measured every 0.1 milepost, while in other projects it was measured every milepost. This implies that the strength of spatial correlation could be project-dependent. Moreover, IRI measurements for each year are generally stable, but in some cases, individual measurement outliers due to road condition and measurement equipment are present, as expected. For example, the data for the first five years for one set of the projects was very unstable. Based on conversations with the DOT, the author learned that these initial five years of data included the time when the agency was implementing a new measurement technology and learning how to best measure and interpret the data. Therefore, these five years of data were removed. To alleviate inhomogeneity in spatial granularities and to reduce the effect of outlying measurements, the analyzed data are aggregated: with consideration of various outlier handling methods, statistical modeling was performed on the annual trimmed means of the original measurements (10% per tail) per direction within each project (Kim 1992).

Table 4.2 Project Characteristics

Unique Dir. Data Set	Proj.	State	Set Number	Dir.	Total Length (Miles)	Pave. Type	Project Type	Project Delivery Method
1	1A	AZ	A	1	3.6	ACP	ReCon	DB
2	1B	AZ	A	2	3.6	ACP	ReCon	DB
3	2A	AZ	A	1	3.2	ACP	ReCon	DBB
4	2B	AZ	A	2	3.2	ACP	ReCon	DBB
5	3A	CO	B	1	11.8	PCCP	ReCon	DB
6	3B	CO	B	2	11.8	PCCP	ReCon	DB
7	4A	CO	B	1	8.8	PCCP	ReCon	DBB
8	4B	CO	B	2	8.8	PCCP	ReCon	DBB
9	5A	CO	C	1	2.0	ACP	ReSurf	DB
10	5B	CO	C	2	2.0	ACP	ReSurf	DB
11	6A	CO	C	1	2.1	ACP	ReSurf	DBB
12	6B	CO	C	2	2.1	ACP	ReSurf	DBB
13	7	MI	D	1	6	PCCP	ReCon	DB
14	8	MI	D	1	11.4	PCCP	ReCon	DBB
15	9	MN	E	1	8	ACP	ReSurf	DB
16	10	MN	E	1	2.7	ACP	ReSurf	DBB
17	11A	MN	F	1	2.5	PCCP	ReCon	DB
18	11B	MN	F	2	2.5	PCCP	ReCon	DB
19	12A	MN	F	1	2.0	PCCP	ReCon	DBB
20	12B	MN	F	2	2.0	PCCP	ReCon	DBB
21	13	MN	G	1	3.9	PCCP	ReCon	DB
22	14	MN	G	1	6.1	PCCP	ReCon	DBB
23	15	MN	G	1	6.1	PCCP	ReCon	DBB
24	16	VA	H	1	1	ACP	ReSurf	DB
25	17	VA	H	1	0.5	ACP	ReSurf	DBB
26	18	VA	H	1	0.8	ACP	ReSurf	DBB
27	19A	WA	I	1	0.8	ACP	ReSurf	DB
28	19B	WA	I	2	0.3	ACP	ReSurf	DB
29	20	WA	I	1	3.3	ACP	ReSurf	DBB
30	21	WA	I	1	8.5	ACP	ReSurf	DBB
31	22A	WA	I	1	0.9	ACP	ReCon	DB
32	22B	WA	I	2	0.6	ACP	ReCon	DB
33	23	WA	I	1	0.3	ACP	ReSurf	DB
34	24	WA	J	1	0.5	ACP	ReCon	DBB
35	25A	WA	J	1	0.6	ACP	ReCon	DB
36	25B	WA	J	2	0.6	ACP	ReCon	DB
37	26	WA	J	1	0.4	ACP	ReCon	DB

4.4.3 Linear Mixed-Effects Model

The peculiar characteristics of IRI, time-related and with spatial correlation, require linear mixed effects (LME) model to determine whether the observed differences in the data are statistically significant. The LME models are successfully applied to diverse spacio-temporal analysis as well as nested data analysis (Beloconi et al. 2016; Li et al. 2017; Kamarianakis et al. 2016; Kamarianakis et al. 2019). LME models are developed to quantify the association of IRI with the following explanatory factors and their interactions: pavement age, project delivery method, pavement type, and project type. LMEs can be viewed as generalizations of project- or direction-specific regression models, which summarize statistical associations when measurements are collected from a group of projects. Compared with conventional regression models, LME provides valid inferences with regard to the significance of the predictors by accounting for nested data structures (e.g.; directions within projects within states). In addition to underestimating standard errors, important relationships involving each level of the data may be missed in a conventional regression model because of the multilevel structure of the data (Holmes Finch et al. 2014). LME addresses this issue. The general LME model considered is formulated as equation (1).

$$Y_{ijkt} = X_{ijkt}\beta + Z_i b_i + Z_{ij} b_{ij} + Z_{ijk} b_{ijk} + \epsilon_{ijkt} \quad (1)$$

$$b_i \sim N(0, \Psi_1),\ b_{ij} \sim N(0, \Psi_2),\ b_{ijk} \sim N(0, \Psi_3),\ \epsilon_{ijkt} \sim N(0, \sigma^2 \Lambda)$$

In equation (1), Y_{ijkt} denotes the vector of observed IRI at time t with $t = 1,\ldots,T$, in direction k with $k = 1, \ldots, N$, which belongs to project j with $j = 1, \ldots, M$, in the i^{th} state with $i = 1, \ldots, P$. X_{ijkt} represents the matrix of predictors, while β indicates the vector of coefficients for the fixed-effects, which is of particular interest in this work.

Fixed-effects represent 'average' model parameters, whereas random-effects denote multi-level deviations from 'average' dynamics. Nested random effects structured by direction, project, and state, are captured by $Z_{ijk} b_{ijk}$, $Z_{ij} b_{ij}$ and $Z_i b_i$, respectively. In each case, the random effects are assumed to follow multivariate normal distributions with covariance matrices denoted by Ψ_i, with i = 1,2,3 and the Z matrices allow for random intercepts and slopes for age and age squared. Measurements made on the same direction share the same random effect, hence they are correlated; the same holds for measurements collected for the same project or state. On the other hand, random effects corresponding to different states are assumed independent. The direction-specific error terms ϵ_{ijkt} are assumed normally distributed and independent of the random effects. Their covariance structure aims to capture serial correlation, with Λ specified to correspond to an autoregressive model (Pinheiro and Bates, 2000); this step is necessary as essentially the dataset is comprised of direction-specific time series.

Model selection was performed following the top-down strategy (West et al. 2006), which focuses on the random effects first and then optimizes terms associated with fixed effects (Diggle et al. 2002). The protocol of the top-down strategy is as follows (Zuur et al. 2009).

1. The first step is to build a "beyond optimal regression model" which includes all explanatory variables as fixed effects and as many interactions as possible. It reduces the bias of the random effects because it helps exclude any information that is evoked by fixed effects.
2. The second step is to find an optimal random effect structure given the regression model developed in the previous step. Restricted maximum likelihood (REML) estimation is used for assessing models with nested random effects structures. Decisions on the structure of random effects and their correlation can be based on analysis of variance (ANOVA) tests, or on

information criteria such as the Akaike information criterion (AIC), or the Bayesian information criterion (BIC). Results reported in this chapter are based on AIC.

3. Once an optimal random structure has been derived, the next step is to find an optimal structure for the fixed effects terms. To assess the fixed effects terms corresponding to nested models, maximum likelihood (ML) estimators must be used.
4. Report the final model using REML estimates.

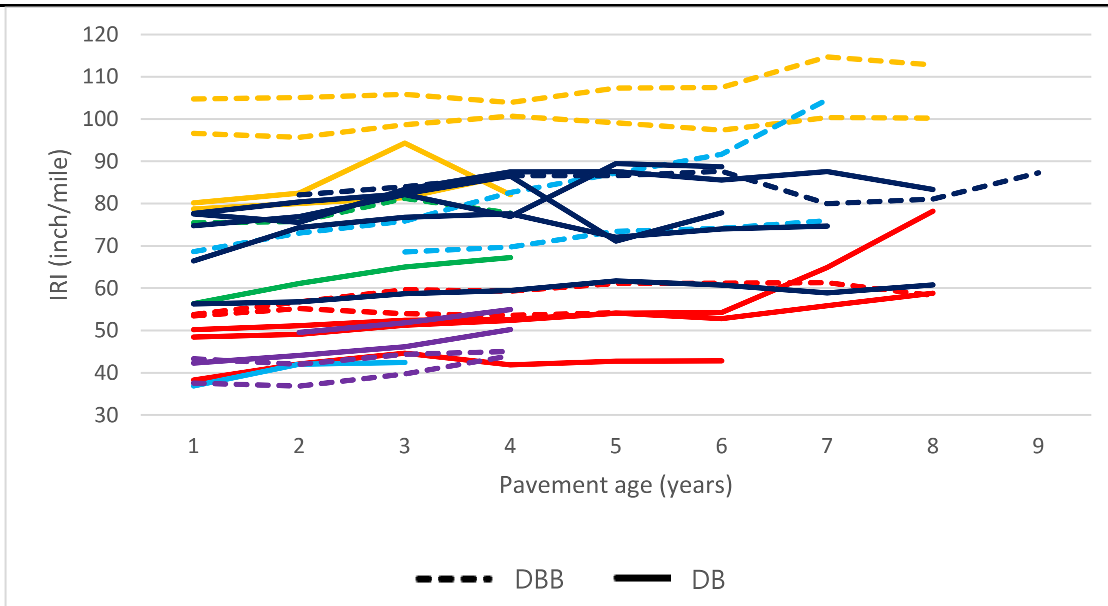
Example applications based on the discussed strategy can be found in Pinheiro and Bates (2000) and Zuur et al. (2009). Next, the chapter discusses the LME results based on using the aforementioned approach.

4.5 LME Modeling Results

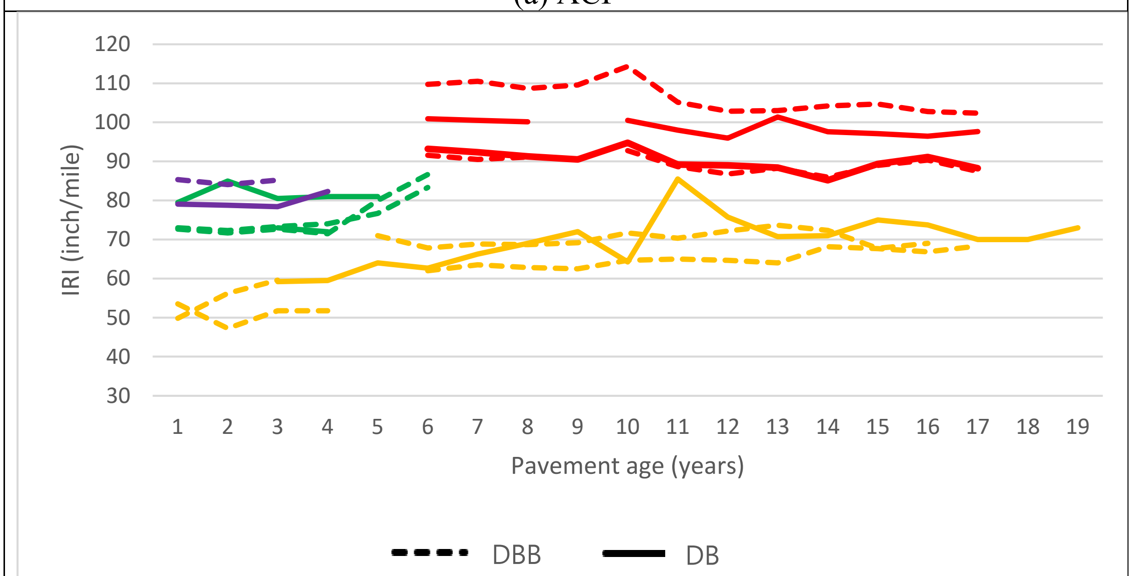
4.5.1 Descriptive Statistics

Before presenting the LME modeling result, this chapter first discusses descriptive statistical analysis to visually observe the data. **Error! Reference source not found.** shows the trends of 20 percent trimmed means per direction within each project, categorized by ACP and PCCP. The same color represents that they are comparable projects, which came from the same region and their characteristics are similar except for their project delivery method. Low values of IRI are associated with better ride quality. In the ACP projects, most of the solid lines associated with DB projects are located below the dotted ones that correspond to DBB projects, which implies that DB projects are performing better than

DBB projects. Lastly, PCCP projects show that it is hard to visually see differences in performance, because some lines of DB are under those of DBB projects, but some are not.



(a) ACP



(b) PCCP

Figure 4.5 IRI Trend per Delivery Method

4.5.2 The Resulting IRI Spatio-temporal Model

As stated earlier, the LME full model considers long-term IRI performance with the various explanatory factors and their interactions. Following a top-down modeling strategy (Diggle et al. 2002), the final reduced model is suggested in this section. The model includes random intercepts and random slopes for IRI change versus age, structured by directions within projects within states. Random slopes are included in this model to allow for different states to have different regressions depending on the rate of change in IRI versus pavement age. The fixed effects in the final specifications include age, project delivery method (0: DB, 1: DBB), pavement type (0: ACP, 1: PCCP), project type (0: Resurfacing, 1: Reconstruction), and an interaction effect between project delivery method and project type. Coefficients (Beta values for fixed effects) are presented in Table 4.3.

$$y_{ijkt} = \begin{matrix} \beta_0 + \beta_1 Age(t) + \beta_2 PDM + (\beta_3 + \beta_4 PDM)PT + \beta_5 Pave + \\ b_{i,0} + b_{i,1}t + b_{ij} + b_{ijk} + \epsilon_{ijkt} \end{matrix} \tag{2}$$

$\begin{pmatrix} b_{1,0} \\ b_{2,0} \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 24.06^2 & 0 \\ 0 & 0.83^2 \end{pmatrix}\right)$, $b_{ij} \sim N(0, 5.80^2)$, $b_{ijk} \sim N(0, 6.33^2)$, $\epsilon_{ijkt} \sim (0, 2.18^2 \Lambda)$, where Λ represents the first order auto-regressive model with parameter ϕ estimated to be equal to 0.67. ϕ is the single correlation parameter, represents lag-1 correlation, which takes values between -1 and 1.

With regard to the interpretation of the final model it should be emphasized that this model is not applicable to compare the performance of ACP versus PCCP pavements, or reconstruction versus resurfacing, because the data collection criteria focused on finding comparable projects based on the project delivery method. Different projects from diverse states might have different treatments (e.g.; grinding, rubberized asphalt) even though their pavement types are the same. However, it is important to check the resulting modeling coefficients to confirm that the model appropriately represents the data. The modeling output shows significant variability in the rate of change in IRI (represented by slopes) with respect to the pavement age for different states; however, within the same state, there is no substantial variability of slopes for different projects and directions. When it comes to intercepts, the observed results suggest that there is significant variability of intercepts across directions, projects, and states; This is in accordance with a-priori expectations as the intercepts correspond to the expected levels of IRI during the first year of each project, which are not equal. Table 4.3 presents the fixed effects coefficients of the final model. Fixed effects denote the average model parameters. In contrast, random effects denote different intercepts and slopes by region, project, and road direction; these are presented in equation (2). Fixed effects coefficients are significant with p-values less than 0.05.

Table 4.3 shows the age variable is correlated with IRI changes of 1.816 inches per mile per year, and this slope is not changed by the interaction with the project delivery method. This means that the project delivery method does not affect the yearly pavement performance changes. It is worth reminding the reader that the results should not be used to compare performance of pavement types and project types because the projects studied here were selected in a way optimized to reduce most variability between comparable sets *except* for the delivery method, which is the focus of this work. The project delivery method shows significant differences between DB and DBB, with 15.982 inches per mile improvements on ACP resurfacing projects based on its intercept. However, the interaction term between project delivery method and project type indicates there is a very small change for reconstruction projects, on the order of 0.408 inches per mile difference between project delivery methods; calculated as *PDM* (15.982) minus *PDM:Project type* (16.390) from Table 4.3. This result can be summarized as DB projects being associated with changes ranging from little impact to increasing the lifespan of pavements up to 8.8 years compared to DBB projects based on the scale of IRI change through a pavement's age.

Table 4.3 Estimated Linear Mixed-Effects Model: Fixed Effects

Variables	Coefficient	Std. error	DF	t-value	p-value
Intercept	50.961	10.721	178	4.754	0.000
Age	1.816	0.402	178	4.518	0.000
Project delivery method (PDM)	15.982	5.466	16	2.924	0.010
Pavement type	-20.807	8.086	16	-2.573	0.020
Project type	28.126	6.509	16	4.321	0.000
PDM:Project type	-16.390	7.075	16	-2.317	0.034

4.6 Estimating Monetary Impacts

Based on the measured IRI improvements, the author expect the DB delivery method used on pavement resurfacing projects to be associated with improved performance on the order of eight years compared to DBB. To analyze the monetary impacts associated with this improvement, a LCCA is performed. In its LCCA policy statement, FHWA advocates setting an LCCA period at least 35 years for all pavement projects, covering new and rehabilitation projects (Walls III and Smith 1998). Using assumptions from LCCA policy statement, an LCCA scenario is presented in Table 4.4. The basic scenario for the DBB project is adopted from PennDOT's pavement design strategy, which is described in Walls III and Smith (1998), and pavement life is considered to be 40 years. The alternative scenario for the DB project is set up the same as DBB, but after the resurfacing, it is assumed it will last five years longer than the original pavement because a usual pavement management plan works in five year improvements. This is a conservative scenario compared to the 8.8 years advantage found earlier.

Table 4.4 LCCA Scenario for ACP

Year	DBB Project Scenario (Walls III and Smith 1998)	DB Project Scenario (Based on IRI improvements)
0	New pavement	New pavement
5	Clean and seal	Clean and seal
10	Clean and seal	Clean and seal
15	Clean and seal	Clean and seal
20	Clean and seal with patching	Clean and seal with patching
25	Clean and seal	Clean and seal
30	Overlay (Resurfacing)	Overlay (Resurfacing)
35	Seal coat shoulders	Clean and seal
40	Reconstruction	Seal coat shoulders
45	Clean and seal	Reconstruction

The net present value (NPV) is selected as an economic efficiency factor. Equation (3) shows the computing method of NPV (Walls III and Smith 1998).

$$\text{NPV} = \text{Initial Cost} + \sum_{k=1}^{N} Rehab\ Cost_k \left[\frac{1}{(1+i)^{n_k}}\right] \quad (3)$$

Where: i: interest rate; and

n: year of expenditure.

The interest rate (i) includes the real interest rate, anticipated inflation, interest rate risk, default risk, prepayment risk, and other risks. These relationships can be summarized in general as following equation (4) (Brueggeman and Fisher 2011).

$$i = r + p + f \quad (4)$$

Where: i: interest rate;

r: competitive with real returns available on other investment opportunities in the economy;

p: a premum sufficiently high to compensate for default & other risks; and

f : reflects anticipated inflation to earn a real rate of interest.

In its "Pavement Division Interim Technical Bulletin," FHWA suggests using a four percent historical interest rate for pavement LCCA (Walls III and Smith 1998). This chapter uses this value and also provides a sensitivity analysis as the results.

The sample project is assumed a one-mile length highway road to consist of four lanes with shoulders. The construction cost is based on the 2014 estimated cost per mile from the Arkansas DOT (Arkansas Highway and Transportation Department 2014). This cost is escalated to a January 2018 monetary value by using the *RSMeans* historical cost index (Gordian 2018). In addition, based on the 2017 national building cost manual, the construction price from Arkansas DOT data is modified by seven percent to estimate the U.S. average construction price (Moselle 2016). The initial construction cost is conservatively assumed the same based on Sullivan et al. (2017)'s meta-analysis of delivery methods impact on project cost.

Table 4.5 shows the monetary impacts based on the LCCA using the different assumed interest rates. Based on the interest rate, the DB has impact ranges from $194,518, when applying five percent interest rate, to $279,606, using two percent interest rate, per one-mile pavement for the next 45 years of highway operation. According to statistics on public road length, the U.S. has 422,510 miles of interstate and other principal and minor arterials with ACP pavement (Bureau of Transportation Statistics 2017). Therefore, the expected total monetary value with a four percent interest rate is estimated at $100.29 billion for the next 45 years, which means U.S. transportation agencies can save $4.84 billion each year. This monetary impact varies from $82.19 billion to $118.14 billion depending on the interest rate. If we assume that the results of this model also apply to local and collector roads, the numbers increase sixfold to $613.73 billion at the four percent interest rate, which equals to $29.62 billon per year. The estimated monetary impacts from this LCCA are conservative based on the assumptions.

The LCCA result gives a brief idea about how different project delivery methods affect road maintenance with monetary value. This can be connected to the ASCE infrastructure report card that shows funding gaps for the next ten years. According to the report, surface transportation needs $1,101 billion for the next ten years, which is equivalent to $135.74 billion per year (ASCE 2017). This means the project delivery method can impact about four percent of the future funding needs and it can make a better chance to improve the overall quality of road infrastructure.

Table 4.5 Sensitivity Analysis of LCCA Based on the Project Delivery Method

Interest Rate	DBB (per one-mile)	DB (per one-mile)	Difference (per one-mile)	Total Monetary Impact	
				Next 45 Years	Annualized
1%	$19,723,857	$19,507,876	$215,980	$91.25 billion	$2.53 billion
2%	$17,074,418	$16,794,812	$279,606	$118.14 billion	$4.01 billion
3%	$15,167,650	$14,894,987	$272,663	$115.20 billion	$4.70 billion
4%	**$13,771,776**	**$13,534,418**	**$237,357**	**$100.29 billion**	**$4.84 billion**
5%	$12,731,314	$12,536,796	$194,518	$82.19 billion	$4.62 billion

4.7 Discussion: Potential Reasons for DB's Improved Performance

The results of this work show that long-term performance of asphalt concrete pavements can be considerably different depending on the project delivery method used. This chapter's scope did not include an investigation of the reasons for these differences, which is the subject of a future investigation, but it is nonetheless necessary to discuss the potential reasons behind these newly-uncovered significant performance differences. Please note that this discussion only lists potential reasons for the observed difference in performance; these reasons are not tested yet and would need a future investigation to study in detail and identify their root causes.

Reasons could include DB projects possibly having different quality processes, different warranty expectations, different contract clauses related to quality, or due to the builder's early timing of engagement in DB, which can lead to improved planning and input to the design (Allen 2001; Anderson and Russell 2001; El Asmar et al. 2013; Francom et al. 2016). Moreover, builders selected through a DB procurement process, which often emphasizes qualifications and prior experience, may indeed have better performance than the lowest bidder typically awarded in DBB projects (Culp 2011).

There have been discussions of the significant role of quality assurance / quality control (QA/QC) in different project delivery methods (Molenaar et al. 2015). QA/QC activities in DBB rely on a system of checks and balances that exists between design and construction. Conversely, a large portion of QA/QC in DB is in the hands of the design-build entity which acts as the single point of responsibility for both design and construction quality (Uhlik and Eller 1999). Papajohn et al. (2019, 2020) surveyed most state transportation agencies that use DB and stated that many agencies do not fully rely on the DB contractor (nor the third party hired by the contractor) for QA/QC, and the agencies still perform their own additional verification. These references prove that there are different applications for the QA/QC process depending on the project delivery method used, although agencies require contractors to meet their quality standards regardless of the delivery method used.

4.8 Conclusion

Performance impacts of project delivery methods have been studied for more than two decades. These impacts have mostly focused on project performance. This chapter, for the first time, quantitatively investigates long-term performance impacts on the lifecycle of the built facilities. The chapter quantifies and presents a significant relationship between project delivery methods and long-term pavement performance in terms of IRI. The author developed an LME model using 37 unique directional data sets representing 26 completed projects from six states after carefully categorizing the data with model selection criteria to ensure data consistency, remove biases, and obtain comparative project sets. The statistical model include the following nested random effects: state, projects nested in a state, and directions nested in a project. The fixed effects are: pavement age, pavement structure, project type, project delivery method, and one interaction term for the project delivery method and project type. The final model reveals that DB provides a statistically significant 15.982 in/mile superior performance when compared to DBB on ACP resurfacing projects. However, there was a very small difference for reconstruction projects. Finally, the approximate monetary impacts of the improved performance potential are estimated on the order of $100 billion in maintenance costs on the U.S. NHS over a 45-year lifecycle.

The main limitation of the study is that the results are based on the sample of data collected. At the same time, the chapter provides a rich and diverse set of pavement projects to help understand and quantify, for the first time, the impact of delivery systems on long-term performance of built facilities. Future work will include collecting more data for subsets of the IRI analysis, adding more pavement performance features, including additional variables and states, and developing a more accurate estimate of the monetary impacts of time-based modeling of lifecycle pavement performance. In addition, qualitative research will be performed to identify reasons why different project delivery methods result in different long-term facility performance. Finally, it would be interesting to see whether similar long-term performance improvements can be measured for other sectors such as the building or industrial sector.

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5. USE OF END OF LIFE DATA: QUANTITATIVE ANALYSIS

5.1 Abstract

The built environment is accountable for a substantial share of global waste production. Construction and demolition (C&D) debris requires significant landfill areas and costs billions of dollars. New business models that reduce this waste may prove to be financially beneficial and generally more sustainable. One such model is referred to as the "Circular Economy" (CE), which promotes the efficient use of materials to minimize waste generation and raw material consumption. CE is achieved by maximizing the life of materials and components and reclaiming the typically wasted value at the culmination of their lifespan. This chapter builds on the existing CE model by identifying opportunities for using CE in the built environment. This study identifies three recycling steam entities and estimates the monetary benefit of recycling C&D debris for each of them: waste generators, recyclers, and end-users. The result shows that waste generators can save $6.5 billion by recycling, in comparison to sending the current waste materials to landfills. This study could not find the estimated monetary benefit for recyclers, but reasonable profit should be generated for them to sustain the C&D recycling industry. Lastly, end-users benefit an estimated $34 billion, which can be achieved based on the condition of high-value recycling materials. This study presents the economic benefit of recycling C&D waste, on a macro scale, and discusses how to increase the C&D debris recycling in the U.S.

5.2 Introduction

The construction industry is the world's largest virgin materials consumer, consuming more than 3 billion tons per year of virgin materials (World Economic Forum (WEF) 2016). For instance, the construction industry stands responsible for 50 percent of global steel consumption (ARUP 2016). The United States Environmental Protection Agency (U.S. EPA) (2019) estimates that in 2017, around 268 million tons (considered as U.S. short tons, if it is not specified separately) of municipal solid waste (MSW) and 569 Million tons of construction and demolition (C&D) debris were generated. Still, the U.S. recycling rate is 35 percent (2017 data) for MSW and 75 percent (2015 data) for C&D debris (U.S. EPA 2018, 2019, 2020).

C&D debris is defined separately from MSW by the EPA. MSW consists of thirteen materials by residential waste, including waste from significant family housing and waste from businesses and organizations. The primary sources are packing boxes, food leftovers, lawn trimmings, furniture and fittings, spoiled electronics, tires, and appliances. In comparison, C&D debris results from construction, renovation, and demolition events for roads, buildings, bridges, and other structures. The EPA collects data on seven C&D materials: wood products, concrete, asphalt shingles, drywall and plasters, steel, brick and clay tile, and asphalt concrete.

The high volume of C&D debris is a motivating factor for this research studying how the large waste streams can potentially become financially beneficial through applying the concept of Circular Economy (CE) to the construction industry. According to the Construction and Demolition Recycling Association (CDRA), C&D debris in the U.S. alone requires 4,356 acres of landfill area 50 feet deep, every year (Townsend et al. 2014).

Arguably the best C&D debris management practice is to reduce the volume of debris generated from construction or demolition sites (Peng et al. 1997). However, avoiding waste generation is difficult in the construction industry (Yuan and Shen 2011). Therefore, the next best option is to manage debris by reusing or recycling them to avoid landfilling. CE is a concept that maximizes the opportunity to incorporate recycling, reusing, and refurbishing strategies throughout the construction lifecycle, in order to optimize resource consumption. CE's goal is to close the resource loop to achieve zero waste.

C&D debris from construction sites can be managed in three ways: (1) it can either be sorted on-site where part of the waste is recovered for reuse on-site or taken to recycling facilities, while the rest is taken to landfills; or (2) the C&D waste can be sorted off-site; (3) the last and least sustainable way would be hauling the waste to landfills directly (Hossain et al. 2017). Studies have shown that on-site sorting of debris is the best option for C&D debris management and can reduce environmental impacts by 63 percent due to the possibility for secondary reuse on-site (Hossain and Thomas Ng 2019).

Waste management activities can be viewed as opportunities for construction companies, which can be used to provide competitive bids and improve their public image (Yuan et al. 2011). Reusing of C&D debris also offers potential advantages for facility owners. If a building is pursuing Leadership in Energy and Environmental Design (LEED) certification, LEED includes a requirement to recycle or salvage C&D debris (U.S. Green Building Council 2020). Therefore, it is crucial to initiate and implement a strategic C&D waste management plan that recognizes the materials to be diverted into recycling or disposal. The LEED credit requires at least 50 percent recycling or salvaging rate, to earn 1 credit, while achieving more than 75 percent will earn 2 credits.

At the same time, data from the EPA data shows that a majority of the C&D debris is not recycled, especially when looking at the recycling rates for gypsum, asphalt shingles, and brick and clay tiles being less than 20 percent of the total generated debris (U.S. EPA 2019). Compared to those materials, the recycling rates for concrete, steel, and asphalt concrete are significantly higher, with the EPA data showing more than 80 percent of debris are recycled. El Asmar et al. (2018) states that if recycling and reusing C&D debris can generate significant monetary benefits, it is essential to estimate and showcase these benefits to drive the adoption of circular economy even further in the construction industry. The economic analysis on C&D debris recycling provides a future waste management strategy by understanding current C&D debris practices and finding the method to apply this plan widely. This chapter estimates the economic value of recycling for diverse stakeholders involved in the C&D waste management stream by applying CE. The business and financial side of sustainable C&D waste management is critical for industry stakeholders considering implementing CE practices, especially if they can financially justify the use of environmentally-friendly practices. A lack of economic alignment can hinder sustainable waste management activities.

5.3 Circular Economy in the Built Environment

The Ellen MacArthur Foundation (EMF) (2017) defines a CE as a process that keeps products, components, and resources at their maximum value and in use. In a CE, waste is factored as a valuable output and feeds into a process to add value as an input. CE follows three significant principles: preserve and boost natural capital, optimize supply yields, and foster system efficacy. A CE's success depends on adopting these principles to achieve the best outcomes from the circularity of materials.

With regards to the CE principles, three different business models can be applied to the current material value chain in the built environment: (1) circular design, (2) circular use, and (3) circular recovery (Carra and Magdani 2017). “Circular design” reframes product design from its current linear process to a circular process by exploring social, cultural, natural, and human capital (Ellen MacArthur Foundation 2017). In the built environment, circular design can be applied by selecting circular materials during the design stage. In comparison, “circular use” works on retaining the value of constructed facilities. Some examples of circular use in the built environment are lifetime expansions and platform sharing. Finally, “circular recovery” is applied to products at the end of their lifecycle (Gregson et al. 2015; Singh et al. 2016) and can also be applied in the built environment by managing reverse logistics and reusing materials at their highest value.

This study considered both circular design and circular recovery business models. Figure 5.1 provides a holistic view of possible circular recovery business model applications in the built environment (Crowther 2001; Ellen MacArthur Foundation 2013). It shows four types of action: recycling, reprocessing, reusing, and relocation. In this circular model, materials and resources keep circulating in the system and do not lose all their value (contrary to common practice). One of the best ways to reach a CE is to reduce waste through a whole building disassembly and relocation, which is an aggressive strategy that may not be attainable in most applications.

A little less aggressive than relocation is the reuse of components, which applies to more situations. It can be accomplished by disassembling whole building components and reusing them for the same function served in their early life. A case study is presented by Baggio et al. (2017) on renovating a historical school and saving 39 percent of energy consumption and attaining good thermal comfort in the classrooms, while also preserving the historical parts of the building.

Less aggressive than relocation or the reuse of components as-is, is reusing with some reprocessing of materials, which requires reassembling the salvaged materials into system components. For example, structural wood systems can become more valuable when they age, if they remain without any defects because they can be counted as architectural salvages (Rossow 2004). Their selling price can becomes similar or higher than a comparable wooden structure or wooden floor made with virgin material (Elmwood Reclaimed Timber 2020).

If all previous scenarios are not attainable, the last resort on the path towards CE is recycling materials that would turn old building materials into base materials that require reprocessing and remanufacturing. A commonly recycled construction material is recycled asphalt pavement (RAP), which is made up of reclaimed asphalt pavement. Rajib et al. (2020) analyze the performance of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) and find that using rejuvenators on RAP (or RAS) can increase its long-term performance by reducing the rate of cracking. Xiao et al. (2019) investigate RAP's environmental and economic benefits and find that it saves energy, greenhouse gas emissions, and cost.

In general, C&D waste materials are recycled either in closed-loop or in open-loop recycling processes (Hossain and Thomas 2019). A closed-loop system can be defined as a recycling system that puts the materials back into the same product, whereas open-loop recycling uses the material in products different than the preceding ones (Haupt et al. 2017). As seen in Figure 5.1, a closed-loop will achieve the circularity goal in the built environment domain. Open-loop recycling can achieve the circularity goal by keeping the waste materials outside of the landfills, not necessarily in the built environment domain, providing more circularity options. As an example, waste generated by the construction industry can be used in other applications such as using C&D wood waste in landscaping or feedstock (Lennon 2005). Another example is using waste from outside of the construction industry in the built environment such as using powdered glass waste in concrete production (Deschamps et al. 2018; Ellen MacArthur Foundation 2016). A higher priority is given to the reduction of waste from both resource efficiency and waste management perspectives (Hossain et al. 2017; Pacheco-Torgal et al. 2013), requiring both closed-loop and open-loop recycling to reduce waste as much as possible. Geyer et al. (2016) state that closed-loop recycling should not be favored over open- loop recycling and that there should not be any distinction between the two. In different applications, depending on the materials' qualities and quantities, the benefits of either system can vary (Zink and Geyer 2017). In the end, all of this would result in maintaining the value of C&D materials to be reused at the end of their lifecycles, which would make construction a much more sustainable industry.

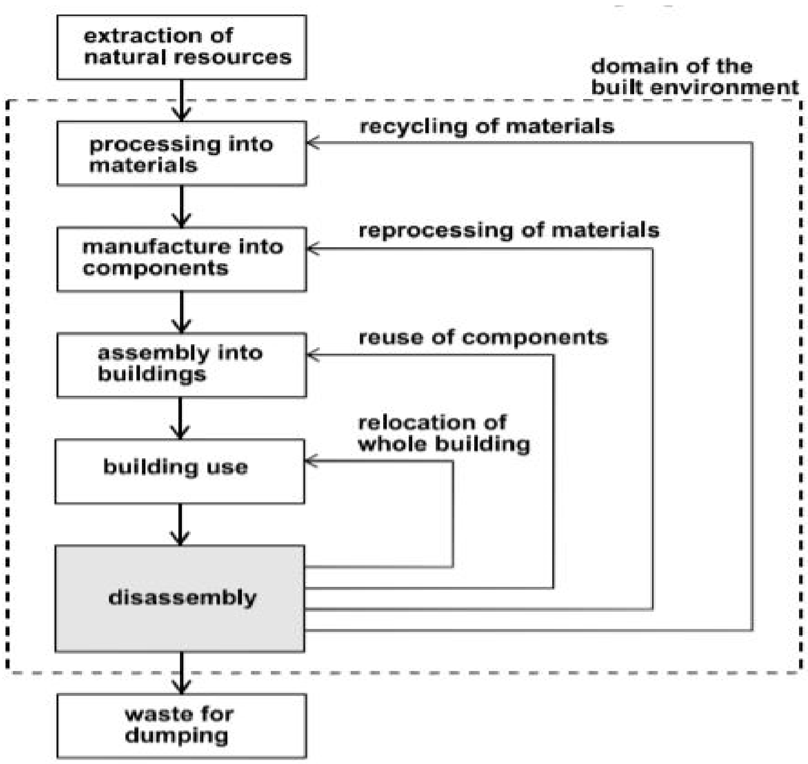

Figure 5.1 Possible End of Life Scenarios for the Built Environment When Adopting CE (Crowther 2001)

Changing the existing frameworks and philosophies in the built environment to CE will have some challenges (ARUP 2016). Some of the obstacles are design and construction challenges for using reclaimed materials and components. That would require the designers to be far more flexible in their design (Fathifazl 2008); also, there may be unpredictable material supply sources, possibly limited product innovation, as well as depreciation issues (Gorgolewski 2008). All of this might also introduce cost or time constraints that need to be considered in construction documents, cost estimates, and project schedules (Gorgolewski et al. 2006). Other challenges are related to the materials themselves.

According to Waste Robotics Inc. (2018), the recovered materials may face challenges, including a lack of markets, in addition to transportation, sorting and cost management complexities and the risk of contamination in mixed materials. However, the efforts may be worthwhile as decreasing the amount of C&D waste discarded in bare landfills would conserve landfill space, reduce greenhouse gases, save energy (Townsend et al. 2014), and possibly generate monetary benefits, as will be quantified in this chapter.

5.4 Current Status of the C&D Debris in the U.S.

Conducting periodical estimates of the C&D debris market's potential, understanding the amount and sources of waste generation, and current recycling practices is a critical step. Table 5.1 shows U.S. C&D debris sources in 2015 and 2017 from the U.S. EPA (U.S. EPA 2018, 2019). The table shows three significant contributors to C&D debris: (1) buildings, (2) roads and bridges, and (3) “others” that include C&D debris from communication, power, railway, sewer, and water disposal, water supply, conservation and development, and manufacturing infrastructure. Note that about ninety-two percent of C&D debris is generated from demolition sites, and 8 percent are generated from construction activities (U.S. EPA 2019).

Table 5.1 U.S. C&D Debris Source Generated in 2015 and 2017; Unit: U.S. Million Ton (U.S. EPA 2018, 2019)

	2015				**2017**			
	Bldg.	**Road and Bridges**	**Other**	**Total**	**Bldg.**	**Road and Bridges**	**Other**	**Total**
Concrete	88.4	158.4	135	381.8	98.8	164.5	133.7	397
Wood Products	37.6*		1.4	39	38.9*		1.3	40.2
Gypsum/Drywall and Plasters	13	-	-	13	15.3	-	-	15.3
Steel	4.5**			4.5	4.6**			4.6
Brick and Clay Tile	12.1	-	-	12.1	12.2	-	-	12.2
Asphalt Shingles	13.5	-	-	13.5	14.4	-	-	14.4
Asphalt Concrete	-	83.9	-	83.9	-	85.7	-	85.7
Total	169.1	242.3	136.4	547.8	184.2	250.2	135	569.4

* Wood consumption in buildings also includes some lumber consumed for the construction of other structures. Data were not available to allocate lumber consumption for non-residential and unspecified uses between buildings and other structures except for railroad ties. Since non-residential buildings such as barns, warehouses and small commercial buildings are assumed to consume a greater amount of lumber than other structures, the amount of lumber for construction remaining after the amount for railroad ties is split out is included in the buildings source category.
** Steel consumption in buildings also includes steel consumed for the construction of roads and bridges. Data were not available to allocate steel consumption across different sources, but buildings are assumed to consume the largest portion of steel for construction.

Based on the values provided in Table 5.1, there is a slight increase in the amount of C&D debris from 2015 to 2017. The total amount of waste increased by about 4 percent; the amount of gypsum/drywall and plasters increased by about 18 percent; and asphalt shingles increased by about 7 percent. By far the largest portion of C&D waste comes from concrete. Gypsum/drywalls and plasters, brick and clay tile, and asphalt shingles waste comes from building C&D activities. Asphalt concrete debris are generated from roads and bridges. Most wood C&S waste are generated from building sections because working and farming buildings such as barns, warehouses, and micro-enterprise buildings use a substantial amount of lumber for construction (U.S. EPA 2019).

The U.S. EPA (2020) analyzes the processing flows of C&D debris, as shown in Table 5.2, which estimates the amount of reclaimed debris with respect to 2015 data. The subsequent use consists of five activities: manure and mulch, industrial products, aggregate and other, fuel, and soil amendment. Table 5.2 shows the reuse or recycling rates of concrete, steel, and asphalt concrete, which are over 80 percent; but the reuse or recycling rates for wood products, gypsum/drywall and plasters, brick and clay tile, and asphalt shingles are less than 15 percent. These results present that waste generated from the building site is not well recycled (Table 5.1). Compared to the U.S. EPA's 2009 data, the total recycling rate increased from 20-30 percent to 75 percent. The C&D waste portions that end up in landfills changed significantly. For example, the portion of lumber that goes into landfill was 40 percent of the total landfill by weight in 2009, but its portion in 2017 was about 20 percent. On the other hand, concrete and brick were responsible for 10 percent of the entire landfill by weight in 2009, whereas this number in 2017 was closer to 50 percent, even though the recycling rate for concrete is about 85 percent. This difference is from the increase of total generated C&D debris, such as 160 tons of waste generated in 2009, while 547.8 tons of waste was generated in 2015 (U.S. EPA 2009, 2018).

A report on waste statistics of South Korea shows that concrete, asphalt concrete, bricks and block, and metals have a recycling rate of over 99 percent (South Korean Ministry of Environment and Korea Environment Corporation 2018). The same report shows wood's recycling rate is 96 percent recycled, and the remaining 4 percent is used as fuel. Lastly, gypsum/drywall and plasters' recycling rate is about 80 percent. This comparative data clearly shows that the U.S. recycling rates are low for some materials in the C&D waste stream. To set up a recycling rate goal, it is essential to benchmark other cases. This study's goal is for the U.S. to reach the current recycling rates of C&D waste in South Korea. The author calculated the gaps in recycling rates, in percentages, for various materials, as shown in Table 5.3. The recycling goals for the U.S. can be computed based on the total amount of debris shown in Table 5.2 and the gap percentages shown in Table 5.3.

Table 5.2 U.S. C&D Debris Recycling Rate in 2015 (Unit: Million Ton) (U.S. EPA, 2020)

	Landfill	Next use						Total	Reuse /Recycle rate (%)
		Compost and Mulch	Manufactured Products	Aggregate, Other	Fuel	Soil Amendment	Total Next Use		
Concrete	66.5	0	31	284.3	0	0	315.3	381.8	82.58
Wood Products	27.1	2.6	1.3	0	8	0	11.9	39	30.51
Gypsum/Drywall and Plasters	10.8	0	0.2	0	0	2	2.2	13	16.92
Steel	0.7	0	3.8	0	0	0	3.8	4.5	84.44
Brick and Clay Tile	10.6	0	0	1.5	0	0	1.5	12.1	12.40
Asphalt Shingles	11.5	0	1.9	0.08	0.02	0	2	13.5	14.81
Asphalt Concrete	5.8	0	70.3	7.8	0	0	78.1	83.9	93.09
Total	133	2.6	108.5	293.68	8.02	2	414.8	547.8	75.72

Table 5.3 U.S. Comparison of C&D Debris Recycling Rate from EPA Data and South Korea in 2015; Unit: U.S. Million Tons (South Korean Ministry of Environment and Korea Environment Corporation 2018; U.S. EPA 2020)

	Recycling Rate (U.S.)	Recycling Rate (South Korea)	Gap	Goal of Recycling (Million ton)
Concrete	82.58%	99.91%	17.33%	66.2
Wood Products	30.51%	96.10%	65.59%	25.6
Gypsum/Drywall and Plasters	16.92%	80.41%	63.49%	8.3
Steel	84.44%	100.00%	15.56%	0.7
Brick and Clay Tile	12.40%	99.65%	87.26%	10.6
Asphalt Shingles	14.81%	No data	-	11.5
Asphalt Concrete	93.09%	99.90%	6.82%	5.7
Total	75.72%	98.06%	22.34%	128.5

In addition to the variations in recovery and reuse rates for different materials nationally, recycling and reusing C&D debris vary significantly from one location to the next. Table 5.4 shows the recycling rates of construction and demolition waste in different states and cities in the U.S. Some states are achieving high levels of recycling of C&D waste (e.g., Massachusetts), while other states have much lower recycling and reuse rates (e.g., Virginia). This discussion will highlight the actions implemented by states and cities with high recovery rates to achieve these high rates. These successful models are then formalized as acceptable practices that states and cities with low recycling and reuse rates can adopt to enhance their material recovery rates.

Table 5.4 Sample of C&D Debris Recycling Rates in America

City or State	C&D disposal	C&D recycled	Total	% recycled	References
Florida	4,422,861	3,097,791	7,520,652	41%	(Townsend et al. 2014)
Maine	329,562	54,960	384,522	14%	
Maryland	1,452,670	196,164	1,648,834	12%	
Massachusetts	440,000	2,250,000	2,690,000	84%	
South Carolina	2,894,242	690,826	3,585,068	19%	
Texas	4,972,998	408,256	5,381,254	8%	
Virginia	3,476,690	309,996	3,786,686	8%	
Washington	2,115,982	3,655,698	5,771,680	63%	
New York	2,125,422	2,075,174	4,200,616	49%	(Griffith 2009)
San Francisco, CA	-----	-----	-----	65% (Mandatory)	(Lee and Raphael 2014)
Portland, OR	-----	-----	-----	75% (Mandatory)	(Elder Demolition 2015)

Two cities and two states with high recycling and reuse rates are studied to identify strategies or acceptable practices adopted to enhance recycling/reuse rates. These are the states of Massachusetts and Washington and the cities of Portland, OR and San Francisco, CA, as shown in Table 5.5. The strategies listed in Table 5.5 are not meant to be comprehensive but rather illustrative of the types of acceptable practices that could be adopted by other cities or states. Some of these strategies used by the high-performing states and towns are discussed next. Table 5.5 presents the regulatory and economic strategies by the group.

Table 5.5 Used C&D Waste Recovery Strategies in States and Cities

Location	**States**		**Cities**	
	Massachusetts	**Washington**	**Portland, OR**	**San Francisco, CA**
Current C&D waste recovery rate	**84%**	**63%**	**75%**	**65%**
Identified Strategies				
1. Governmental regulations determining the minimum diversion percentages		X	X	X
2. Waste disposal ban	X			
3. Increased landfill tipping fees	X	X	X	X
4. Local funding to recycling and waste management programs			X	X
5. Well-developed and growing recycling industry with many recycling facilities	X	X	X	X

Regulatory strategies include regulations on minimum diversion rates from the landfills, as used in Portland, Seattle, and San Francisco (Lee and Raphael 2014; Elder Demolition 2015; Seattle Public Utilities 2017). This regulation was applied to metals, cardboard, wood, land- clearing debris, concrete, and masonry, and reported that builders receive benefits associated with recycling C&D waste, including tax deductions when donating salvage materials, lower tipping fees, and financial services from selling the recovered materials (City of Portland 2018). Besides, banning some waste disposal also helps to increase recycling rates. The Massachusetts Department of Environmental Protection amended its regulations in the year 2006 to include asphalt pavement, brick and concrete, metal, and wood to its waste disposal ban, meaning these materials are not allowed in landfills (DSM Environmental Services 2008). In the same report, the wood disposal ban recovered 667,000 tons of wood waste sent to landfills, which is accountable for 31percent of the total C&D waste. The current recycling rate in Table 5.4 proves that these aggressive approaches work to enhance recycling in long-term purpose.

In addition to regulations, economic strategies are also being implemented successfully. First, increasing landfill tipping fees directly reduces the amount of landfilled waste. The landfill tipping fee for Massachusetts state is about 80 percent higher than the national average during 2018, and Washington state is also about 60 percent higher (Staley et al. 2019). San Francisco's disposal rates are approximately $200.51 per ton, 280 percent higher than the national average, and 250 percent higher than California state average (Recology 2017; Staley et al. 2019). Second, local funding for recycling and waste management programs also boosts waste recovery. San Francisco and Portland's cities support financial grants to encourage recycling (Resource Recycling Systems 2017; City of Portland 2018). Finally, a well-developed and growing recycling industry help increase recycling rates. Portland's city builds a well-developed recycling economy with its long history of recycling effort, which contributed to the high levels of C&D recycling (Rathmann 1997).

The national trend and status of C&D debris recycling show a clear gap. Specifically, Table 5.1 and Table 5.2 clearly show that the materials only generated from the building site, such as gypsum and asphalt shingles, have lower recycling rates compared to others. The international case from South Korea and various U.S. state and city level policies clearly show that this gap can be overcome. This study estimates the economic benefit of C&D debris recycling in the U.S. when the recycling gap is overcome with the CE application.

5.5 Research Methodology

This study focuses on estimating the monetary benefit of C&D debris recycling. It estimates the benefit of recycling for three isolated entities, building (facility) owners who generate C&D debris, recycling companies who process the debris, and end-users who are applying reclaimed materials for their projects. These three entities in the recycling stream represent the cradle to the grave C&D waste lifecycle. This chapter uses the statistical data from the U.S. and South Korea. The data from South Korea contains detailed and useful information to provide insight into the U.S. C&D debris industry. For example, the Korea Institute of Applied Statistics (2018) published the cost for waste management, including C&D debris processing cost each year for government contracts. This study applied 2018 data, which used cost data from year 2017.

The data is mixed with different nations and may not provide accurate estimation due to complex market conditions, different labor fees, consumer price index (CPI), currency differences, among other factors. This study applies 2017 cost data and assumes an exchange rate of 1 U.S. dollar equals 1,179 won, equivalent to the average yearly currency exchange rate of 2017 (IRS 2020). Besides, it is hard to compare recycling costs directly converting through the exchange rate because both nations have different purchasing powers. In addition, the gross domestic product (GDP) provides a modification of the exchange rate, but it requires a comparable product, which has a similar value in each of the nations. There is an economic theory called the law of one price (LoOP), but this theory has the limitation that the comparing product should have the exact same price in two different markets, so the cost, taxes, and tariffs cannot be counted in the theory (Jošić et al. 2018). This study uses the Big Mac index, which is usually used as a currency comparison tool in financial analysis that considers both exchange rate and GDP (Yasser et al. 2019). In 2017, the Korean won was 5.6 percent undervalued compared to the U.S. Dollar, based on GDP adjusted data (The Economist 2020). Therefore, the recycling price from South Korea is adjusted for a 5.6 percent increase after the data was converted to U.S. Dollars.

Figure 5.2 shows the process of recycling and entities involved in each process. First, facility owners and contractors, who generate C&D debris, decide to dispose of or recycle C&D debris. This entity will be called a waste generator in this chapter. C&D debris collection fees, transportation fees, and landfill costs should be counted to estimate benefits for waste generators. Secondly, the recycler processes materials for recycling and selling them as reclaimed materials or products. Their benefit is the margin of processing cost of recycling and selling price of reclaimed products/resources. Lastly, from the buyer's perspective, the cost advantage in buying virgin material versus recycled material will be the main discussion point to estimate their benefit.

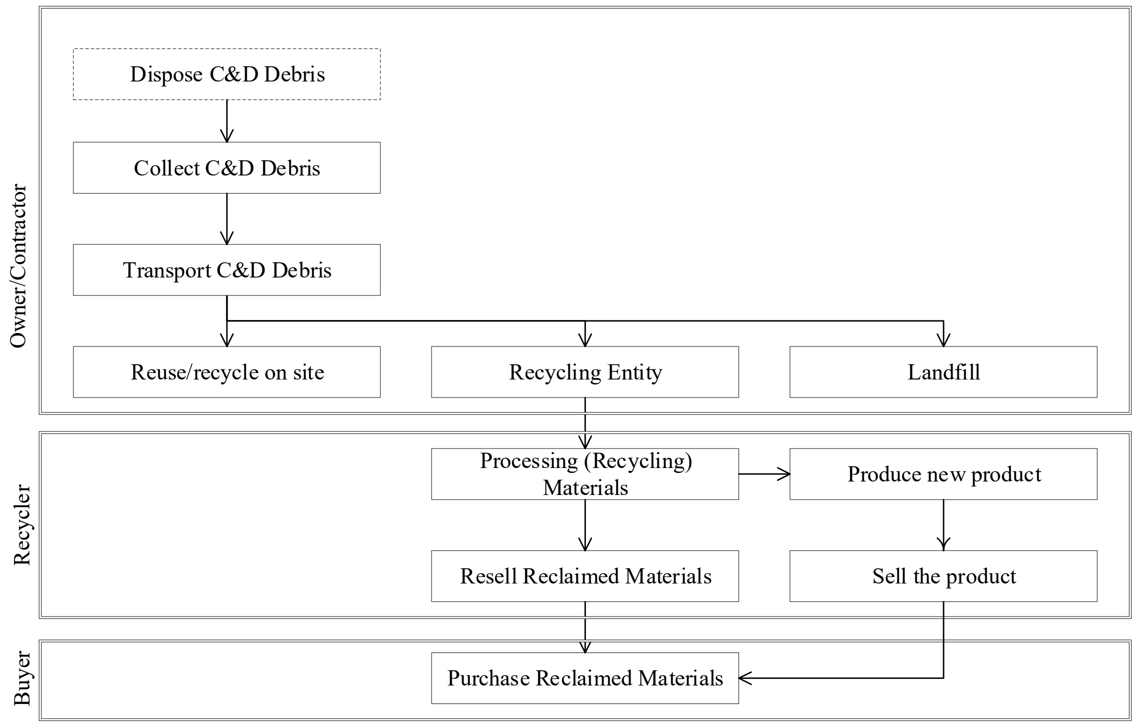

Figure 5.2 C&D Debris Recycling and Reselling Process

This study estimates each entity's monetary benefit. Figure 5.2 will work as a snapshot for each discussion and is further explained in each section. In the next section, this study calculates the financial benefit for recyclers, waste generators, and lastly, buyer's benefit. The recycling entity is mid-stream of the process, so their benefit is linked with both waste generators and buyers.

5.6 Benefits for Recyclers

The recycler's role is to gather the unused or leftover materials from construction or demolition sites, process them, and sell these materials to buyers. The responsibility of collect and transport C&D debris is on the waste generator, so the profit of the recycler depends on the processing fee and its sales price. However, most recycled materials cannot be sold at a more expensive price compared to virgin material costs. Therefore, understanding the cost of processing and selling price of reclaimed materials is essential to estimate their market value.

Table 5.6 shows the breakdown of the C&D debris processing costs. The table presents the itemized categories to utilize processing facility based on the debris coming from each construction or demolition site. Therefore, the cost breakdown structure is developed similar to the construction project cost breakdown structure. The processing cost is organized by material, labor, and overhead costs. It can estimate the total cost of processing by adding general administrative (G&A) expense and profit on top of processing costs. Material costs usually represent the virgin aggregate purchasing costs. However, direct materials are not counted as a cost in the table because the materials are C&D debris. Labor costs are considered both direct and indirect costs. High labor cost is necessary for the recycling industry because the majority of the tasks to process debris cannot be automated. For example, if mixed-waste, waste which is mixed with diverse materials such as concrete, glasses, wood, is delivered to the factory, laborers would have to distribute them by hand. Therefore, for C&D debris that is not separated by the material at construction sites, the recycling processors should distribute them. The G&A cost suggested five percent of material, labor, and overhead cost and profit also recommended as 10 percent in South Korea (Kim 2010). For the U.S. example, Stone (2013) states the G&A cost usually is 5 to 10 percent of the processing cost, and Hoare (2013) suggests a profit estimation of more than 9 percent of the sum of labor cost, expenses, and overhead from the U.S. market. The G&A and profit rates can be different based on the market condition, but the recycling market cannot be sustained without appropriate profits (Agarwal et al. 2005).

Table 5.6 C&D Debris Processing Cost Breakdown (Kim 2008)

Items		**Calculation criteria**
1. Processing	a. Material Costs	
Cost	1) Direct Materials	
	2) Indirect Materials	Gas price
	3) Additions	Aggregate producing cost
	b. Labor Costs	
	1) Direct Labors	Man-hour (hr/ton) x hourly price
	2) Indirect Labors	(M/hr)
		Direct Labors Cost x rate (%)
	c. Overhead Costs	
	1) Other Employee	Meals, personal protective equipment
	Benefits	(PPE)
	2) Electricity (Power	Electricity expense to operate facility
	Rates)	Direct Labors Cost x rate (%)
	3) Utilities	Depends on Depreciation Policy
	4) Depreciation Expense	Direct Labors Cost x rate (%)
	5) Taxes & Dues	Direct Labors Cost x rate (%)
	6) Rent	Worker's compensation and employer's
	7) Insurance Expense	liability insurance
		Machines, equipment, and tool
	8) Repairing Expenses	2^{nd} generated waste while processing
	9) Waste Management	
	Expenses	Articles to maintain machines and
	10) Articles of	equipment
	Consumption Expenses	
2. General Administrative Expense		(a + b + c) x 5%
3. Profit		(b + c + 2) x 10%
4. Total Cost		1 + 2 + 3

Based on the cost breakdown shown in Table 5.6, the Korea Institute of Applied Statistics provides C&D debris processing prices each year for the government contract. They do not provide a detailed cost breakdown, but the report presents its final cost based on the calculation from the reclaimed material's price subtracting the total processing cost. Table 5.7 shows the C&D debris processing price in South Korea, calculated using 2017 data. Note that this price already counts the profit of selling reclaimed aggregates. Table 5.7 presents that all expenses are more extensive than zero, which indicates processing fee is usually higher than the selling price. This means that the waste generator should pay the rest of the cost.

The table also shows the different processing costs for the waste generated from road and bridges versus buildings. In general cases, C&D debris generated from road and bridges are pure materials, but debris from buildings are mixed with diverse materials. Therefore, even though the same materials go to the recycling process, processing cost is significantly different by sources. Moreover, if the C&D debris generated from building is mixed with flammable waste or based on mixtures, the processing cost is significantly different. Due to this constraint, some U.S. waste processing factories collect the C&D waste, denying building debris, for example, Reece Company in the U.S.

Table 5.7 C&D Debris Processing Price in South Korea, 2017 Cost (Korea Institute of Applied Statistics 2018)

Source	Materials	Status	Cost ($ per ton)
Road and Bridges	Concrete	Pure concrete from structure	$18.94
	Asphalt Concrete	Pure asphalts from road pavement	$19.72
Buildings	C&D Debris	C&D debris (concrete, asphalt, brick, and clay tile) without any flammable wastes	$32.08
	Mixed C&D Debris	C&D debris contains 5% of flammable wastes	$46.87
		Glasses/brick/clay tile contain 5% of flammable wastes	$105.42
		Gypsum/drywall and plasters contain 5% of flammable wastes	$109.22

The data presented above is incorporated with the case study result from the Institution Recycling Network (IRN) for the Boston area (Lennon 2005). This report shows the Boston area cost of C&D recycling versus disposal and presents the recycling cost for asphalt shingles as $40 per ton, compared to concrete, brick, and block as $10. It also offers mixed debris recycling costs at $60 per ton, but it did not specify diverse debris. This example shows Table 5.7 can be applied in the U.S. case.

This study assumes that most debris that is not in the current recycling process is from building construction based on the analysis result from Table 5.1 and Table 5.2. Considering the national average of landfill tipping fees in 2017 is $51.82, debris generators may refuse to participate in some of the recycling of mixed C&D debris recycling, such as glasses, brick, clay, gypsum/drywall, and plasters (Staley et al. 2019). Note that the South Korean government increases the C&D debris recycling rate by increasing its landfill tipping fee and C&D recycling law to limit the amount to go to landfill. They charge the increasement of landfill tipping fees by tax and re-invest the money to improve the recycling industry market. Therefore, the ultimate benefit of recycling should be connected with policy.

The shortage of data does not allow for the estimation of monetary benefit for recyclers. The data presented in Table 5.7 only provides the balance of recycling and selling price of recycled materials. A case from South Korea in Table 5.6 presents about ten percent profit for recyclers operating a recycling facility. The profit rate can be changed based on the market competitiveness and conditions, but a reasonable profit should be allocated for recyclers to build a sustainable C&D recycling market.

5.7 Benefits for C&D Debris Generators

C&D debris generator is referred to facility owner and constructor. Generator's side of benefit can be counted by waste collection fee, transportation fee, saving the cost of reuse/recycling C&D debris in the site, price to recycling entity, and landfill tipping fee. This study assumes that usual contractors using recyclable materials on site. Although the U.S specific data is unavailable, the general demolition cost is available. For example, the college laboratory's average demolition cost requires $2.08 per square foot, and a parking garage needs $0.50 per square foot (BuildingJournal.com 2020). The condition of the building can affect these average costs. However, no data available to compare demolition costs when it is performed on-site recycling distribution. U.S. EPA provides the national landfill tipping fee, and the 2017 average is $51.82 per ton (Staley et al. 2019).

South Korea Ministry of Strategy and Finance contracted with the Korea Institute of Applied Statistics and published C&D debris collection, transportation, and processing costs. Specifically, collection and transportation fees include detailed estimation based on the 15-ton dump truck with distance from 30 km to 60 km and the assumption of C&D debris volume and specific gravity. For example, when the C&D debris goes to the recycling entity, each 15-ton dump truck can load 15 tons of waste, but only 6.3 tons can be loaded for the waste going to landfills because it can contain the truck's volume of $10m^3$. The primary reason for this difference is that C&D debris should be distributed and selected because the recycling entity is different based on materials. However, landfill does not require this process because its processing will be performed at the landfill site using a tipping fee.

Table 5.8 shows the total required processing cost for waste generators in the U.S. calculated by the cost data presented in Table 5.7. Again, the information is calculated founded on the supposition that most generated wastes are from building construction sites rather than infrastructure based on the discussion on Table 5.1 and Table 5.2. When all C&D debris is recycled, the total required process cost, which the debris generator needs to be paid, is $5.91 billion. However, some materials, including gypsum/drywall, and plasters and brick and clay tiles, can be dropped from the recycling decision for waste generators as the payment for recyclers is higher than the average tipping fee for landfill. Therefore, if those items are not considered for recycling, $3.90 billion will be paid by the waste generator, and the rest of the materials will be sent to the landfill site.

Table 5.8 Total Required Processing Cost for Waste Generators in the U.S.

	Debris to Recycling (Million ton)	Payment for Recyclers ($ per ton)	Total Payment for Recyclers
Concrete	66.2	$ 32.08	$ 2.12 B
Wood Products	25.6	$ 46.87	$ 1.20 B
Gypsum/Drywall and Plasters	8.3	$ 109.22	$ 0.90 B
Steel	0.7	$ 32.08	$ 0.02 B
Brick and Clay Tile	10.6	$ 105.42	$ 1.11 B
Asphalt Shingles	11.5	$ 32.08	$ 0.36 B
Asphalt Concrete	5.7	$ 32.08	$ 0.18 B
Total	128.5		$5.91 B (All applied) $3.90 B (No Gypsum and Brick)

Table 5.9 shows the monetary benefit for facility owners and contractors based on the mix of South Korea data and the 2017 U.S. average landfill tipping fee. The data assume a 30 km (18.6 miles) average distance from the site to the recycling entity and landfill. As discussed, the cost difference between recycling and landfill for both collection and transportation comes from the different unit weight of C&D debris per truck because debris' status is different. Based on the data, if one ton of debris is going to a landfill, it cost $107.63 per ton for a waste generator.

Compared to landfill, recycling cost is counted based on Table 5.8, but it includes two scenarios: (1) all items go to recycling, and (2) gypsum and brick items go to the landfill; therefore, it counts tipping fee $51.82 and increased collection and transportation fee. The counted cost still shows that landfills those two items have more economic benefits for waste generator. The cost difference between recycling and landfill offers about $6.5 billion advantage of recycling, whether or not choosing any scenario (Table 5.9 shows boundary based on these scenarios). This analysis excludes the demolition fee, and the demolition cost can be significantly different based on the site status. In South Korea, the demolition cost is not different because the C&D waste products management plan are mandatory by the law. This means that site debris distribution is compulsory, and the cost is not much different based on the scenario, but the U.S. demolition price may differ.

Table 5.9 Benefit for Facility Owners (Unit: Per Ton; 2015 C&D Debris Data and 2017 Cost Data)

	For Landfill Debris		**For Recycling Debris**	
	Per ton	**U.S. total**	**Per ton**	**U.S. total**
Collection	$2.58	$0.33 B	$1.56	$0.20B - $0.22 B
Transport	$53.23	$6.84 B	$10.17	$1.31 B - $2.12 B
Tipping fees or Processing fees	$51.82	$6.66 B	$37.92 - $46.01	$4.87 B - $5.91 B
Total	$107.63	$13.83 B	$49.65 - $57.74	$7.21 B - $7.42 B
	Gap		$49.89 - $57.98	$6.41 B - $6.62 B

The result clearly shows C&D debris recycling provides an advantage in cost, about $6.5 billion compared to landfill. The processing cost of materials shows that current practice can offer benefits to most materials. Future research requires recycling gypsum/drywall and plasters and brick and tiles to reduce processing costs and enhance it.

5.8 Benefits for End-Users

The benefit of using recycling materials for end-users need to be counted as two different methods: (1) initial payment and (2) life cycle cost analysis (LCCA). For example, Wang performed two research projects to determine the lasting performance of reclaimed asphalt pavements (RAP) and virgin asphalt (Wang 2013; 2016). The research indicates both materials' pros and cons, but it is very hard to determine the maintenance practices.

Moreover, when considering the other materials, such as woods or gypsum, their long-term performance is not visibly counted. This study limits its economic effect in initial payment only, but LCCA should be followed in future studies.

Also, the selling price by wholesalers and retailers has a gap. Most of the C&D debris recyclers might be counted as wholesalers because the selling amount of aggregates or recycling materials are counted in tons. However, some materials, such as woods and gypsum, are hard to measure by wholesaler due to their final products not being a wholesale product.

To count the benefit of recycling, it is essential to study how the materials will be recycled. Figure 5.3 shows how each C&D debris is recycled and processed from diverse references (Ding et al. 2019; Hansen and Copeland 2015; Lennon 2005; Rossow 2004; South Korean Ministry of Environment 2019; U.S. EPA 2007; Yang et al. 2015). For example, drywall can be reused for the same purpose. If they are not re-usable, it can be used either used for soil amendment or mixture for cement. Note that if the arrows are merged to each other (e.g., steel, aluminum, and copper), it can go to either ways (e.g., reuse, recycle, and landfill).

Wood is a significant material for recycling. The un-damaged structural wood becomes more valuable than virgin material because the water containment is reduced by time and its architectural value can be increased by time (Rossow 2004). For example, Elmwood Reclaimed Timber (2020) buys any recyclable wood from its customers and sells processed wood products to the public. Compared to the market price for mulch or fuel is \$12 to \$24 per ton, wood flooring can be sold for \$10,000 to \$11,000 per ton. Similar value can be applied to structural woods, such as dimensional members. It is quite limited to be determined as high-value materials, but it cannot be ignored that some wood materials from the building have a higher value than expected. Currently, 22 percent of recycled woods are used as compost and mulch, 11 percent used for manufactured products, and 67 percent used for fuel in the U.S. (Table 5.2). Compared to U.S. data, South Korean statistic shows that 4 percent used as fuel and 96 percent of woods are recycled (South Korean Ministry of Environment and Korea Environment Corporation 2018).

Metals, including steel, aluminum, and coppers, are the most valuable recycling materials. They can be melted down and reused for any purpose. Therefore, most metals are already distributed on-site and sold to metal companies. Table 5.3 indicates that only a small portion of metals have flowed to landfill sites, and most of them are reused or recycled.

Processing C&D debris, specifically concrete, brick and clay tiles, asphalt shingle, and asphalt, includes shedding, smashing, and screening aggregates to keep the size of aggregates, consistent. Asphalt and concrete reclaimed products are sold from the company by asphalt aggregate with screened size (e.g., 1.5" – 2.5" and 0" – 1.5"). Bricks can be reused for historic buildings and can be recycled as back-fill aggregates. Asphalt shingles have the most protentional material because they have similar characteristics with asphalt concrete, but do not recycle well. Research performed to evaluate the structural performance and its economic impact using reclaimed asphalt shingles (RAS) pavement (Ding et al. 2019; Hansen and Copeland 2015).

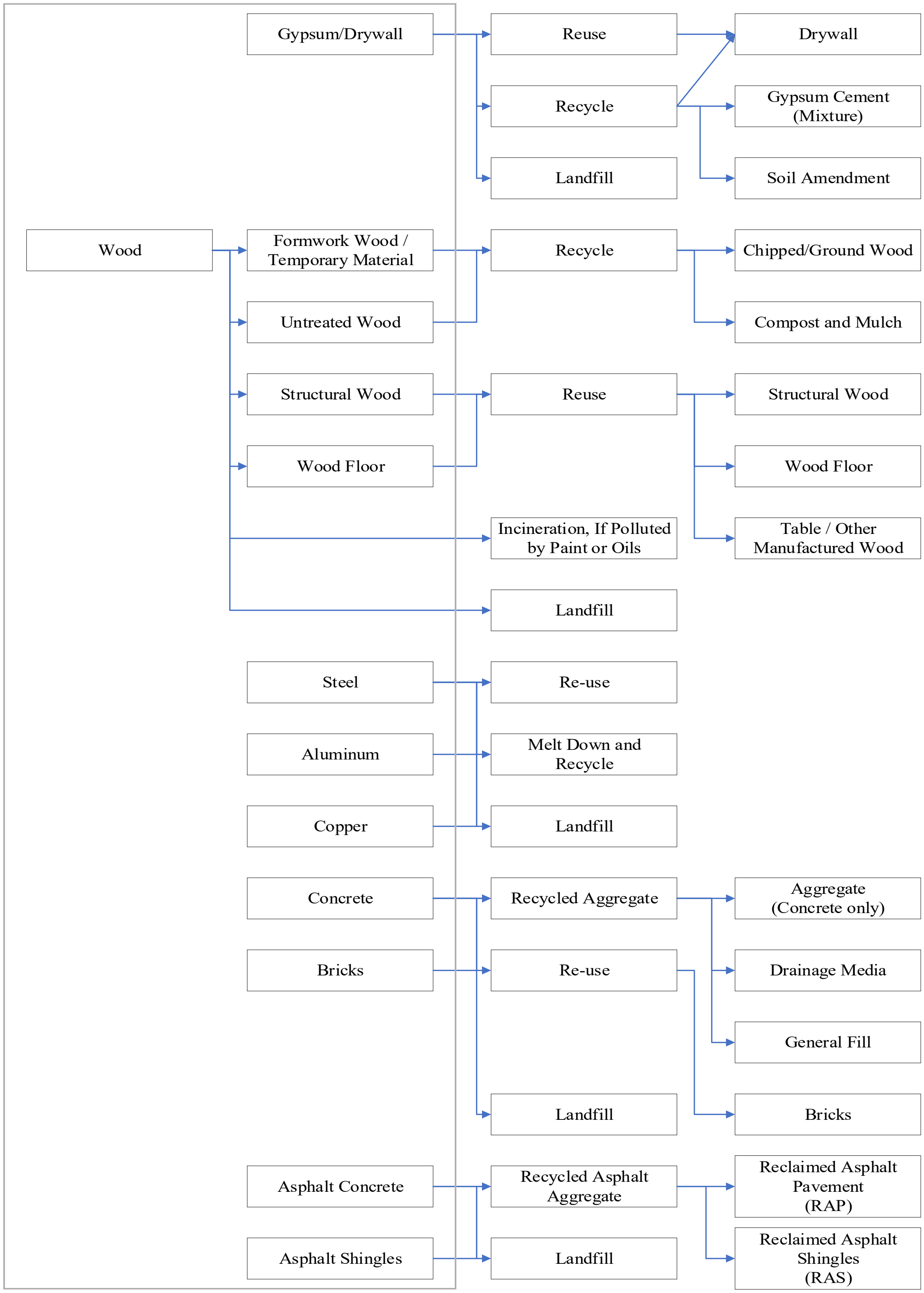

Figure 5.3 C&D Debris Recycling/Reuse Process and Products

Table 5.10 shows the estimated value for end-users based on Figure 5.3. The sales costs for both recycled and virgin materials are calculated by 2020 market value and converted to the U.S. national average by the 2017 national building cost manual (Moselle 2016). Values for the recycled and virgin materials are estimated by using comparable material types, such as the same type of aggregates with the same size or the same type of wood product, and savings are estimated by calculating the difference between them. The data from Table 5.3 estimate the U.S. recycling market value and U.S. national saving value.

First, this study gathered the price for concrete aggregates and recycled clean asphalt aggregate for both recycled and virgin materials from three different sources (C&E Excavating 2018; REECE 2020). Aggregates are sold in 0" – 1.5" size and 1.5" – 2.5" size. All available data are converted to the U.S. average and averaged to the cost presented in Table 5.10. As aggregate, the price for crushed concrete is not different, but recycled asphalt has more savings. From the report by Hansen and Copeland (2015), 30 percent of RAP can save an equivalent amount of asphalt aggregate and asphalt binder. The aggregate and binder ratio is 0.95 versus 0.05, but the binder's price is $294.31 for 2019 cost, which is significantly higher than the aggregate cost.

Some other research projects assess the value of aggregate three to five times higher than asphalt aggregates (Uecker 2014; Zhou et al. 2013). However, since the shingle used the same purpose as asphalt, the price's significant difference is not expected. There may have some gap between the two materials due to the size of aggregate, but the size changes $1 to $2 difference (C&E Excavating 2018; REECE 2020). Therefore, this study presents the same estimated value for asphalt shingles. However, the shingle is coming from the building site, so their processing fee is significantly different. This discussion is presented in the previous chapter.

Brick and clay tiles are not well recycled in the U.S. and they are usually reused for historical building construction projects (Rossow 2004). In addition, there are no research performed use bricks for pavement aggregates, and it is not worth due to the amount of material is very small. In South Korea, bricks are used as back-fill material for the earth retaining wall (South Korean Ministry of Environment 2019). Therefore, this study assumes its market price is similar to concrete aggregate.

In the current recycling ratio for woods shows that they are used for manufacturing about 10 percent. Considering sawdust can be applied to make furniture, they are expected to create higher value than current status. Still, this study limits its high-value percentage as 10 percent and assume most of the price as wood floors. All the other portions are counted as mulch and fuel, and their base price is similar. The price presented in Table 5.10 shows the most significant potential for wood recycling. However, keeping wood material in perfect condition is hard, and polluted wood is not easy to be recycled, specifically if they use paint. Therefore, more than recycling techniques, wood construction, and maintenance techniques should be considered to back-up this market value.

The value for gypsum/drywall and plasters is estimated by the weighted average of nine percent manufactured products and 91 percent soil amendment. Moreover, the type of amendment price also varies by its particle (U.S.A. Gypsum 2020). This study applied an average of these particles and estimated its value. However, the application for soil amendment is not easy to differentiate price by recycling and virgin because their application purpose and its effects are the same. Therefore, this study assumes both prices are similar and did not count its saving value. Steel is also applied similarly to gypsum.

Table 5.10 Benefit for End Users

	Recycled C&D Debris Purchase Price ($ per ton)	Equivalent Virgin Material Cost ($ per ton)	Saving ($ per ton)	U.S. Recycling Market Value ($)	U.S. National Saving Value ($)
Concrete	$9.72	$11.65	$1.93	$0.64 B	$0.13 B
Wood Products	$1,058.27	$2,363.66	$1,305.39	$27.07 B	$33.39 B
Gypsum/Drywall and Plasters	$369.48	$369.48	-	$3.05 B	-
Steel	$312.73	$312.73	-	$0.22 B	-
Brick and Clay Tile	$9.72	$11.65	$1.93	$0.10 B	$0.02 B
Asphalt Shingles	$9.99	$32.73	$22.75	$0.11 B	$0.26 B
Asphalt Concrete	$9.99	$32.73	$22.75	$0.06 B	$0.13 B
			Total	$31.26 B	$33.93 B

5.9 Conclusion

As the global population grows, so is the built environment housing it and the demand for raw materials. These trends motivate the design and architecture, engineering, and construction industry to investigate alternatives to the current linear consumption model and complement it with a more circular model that can provide a stable supply of materials while ensuring the continuity of material flows to future generations. Applying CE to the built environment can help sustain the industry's material supply while providing monetary benefits in the process.

The research estimates the monetary benefit of C&D debris from the U.S., which is not currently recycled but has the potential to be recycled in the future. This study identifies three entities in the recycling stream: facility owners and contractors who generate C&D waste, recyclers, and end-users. The monetary benefit for the three entities should be counted separately because they represent different stages of the recycling process. The difference in waste collection, transportation, tipping fees, and processing fees is considered for waste generators. Compared to sending all C&D debris to landfill sites, recycling provides about $6.5 billion revenue for waste generators if the non-recycled materials are recycled. In the case study from South Korea, recycling entities generate about 10 percent of profit by operating the processing facility for government construction or demolition projects. This study could not count the estimated monetary benefit for recyclers, but reasonable profit should be allocated to build a healthy C&D recycling industry in the U.S. The C&D recycling market cannot be sustained without the participation of recyclers. Lastly, for end-users, it is necessary to have reason to buy these recycled materials. The analysis shows that potentially $34 billion can be saved if end-users use recycled materials or products. However, advanced construction and maintenance are required to improve recyclable materials for achieving this value.

The limitation of this study is that no field study is performed to estimate monetary benefit for C&D debris. Based on the condition of materials, their recycling value can vary. Lastly, since this study only focused on C&D costs, the schedule side should be inspected to increase recycling applications. Another crucial aspect of the recycling process that was not featured well is the effect of these constructions on the environment. The chapter focused more on the cost and benefit of recycling these wastes and the supply of the products to the market, but an equal emphasis needs to be placed on protecting the land on which we build on. Future studies should address these limitations.

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6. CONCLUSION

6.1 Summary of Research

This dissertation explored use-inspired research using data generated from each key project lifecycle phase, while also gauging the impact of the work on construction practice. The project phases investigated include planning, design, construction, operation and maintenance (O&M), and end of life (EOL). The work spanned various construction sectors, including large industrial construction and transportation infrastructure.

Starting with the planning phase, Chapter 2 developed the project definition rating index (PDRI) maturity and accuracy total rating system (MATRS) for large industrial projects using front end planning (FEP) data. Chapter 3 analyzed literature and current practice of earned value management system (EVMS) implementation and execution to provide a basis for improving the reliability of project control data, which span the planning, design, and construction phases. Chapter 4 quantified the impact of project delivery methods on long-term pavement performance by analyzing O&M data. Chapter 5 quantified the monetary impact of circular economy (CE) applied to construction and demolition (C&D) waste in the U.S. Each chapter in this dissertation led to distinct contributions to the body of knowledge. The following section provides a summary of these research contributions and impact.

6.2 Summary of Contributions and Impact

The high-level contribution of the work is demonstrating how construction data can be used across the construction lifecycle, result in impact on construction practice. The detailed list of contributions and impact associated with each chapter of this dissertation is shown in Table 6.1.

The major contribution of Chapter 2 is the development of the PDRI MATRS version 5, which can assess FEP Maturity and Accuracy for large industrial projects. This tool provides objectivity and consistency to the scoring through detailed descriptions of each possible definition level tailored to each of the 70 PDRI elements. In addition, it provides tool utilization guidance based on analyzing cost and schedule growth. The study analyses the data from 32 recently completed large industrial projects representing over $8.77 billion worth of construction. One measured impact of the work includes finding that high maturity and high accuracy (HMHA) projects present their cost performance two percent below budget on average, which is superior to low maturity and low accuracy (LMLA) projects, which have 22 percent above budget, as well as high maturity and low accuracy (HMLA) projects that have 6 percent above budget. In addition, the cost change range significantly reduced from 47 percent range (LMLA) to 18 percent (HMHA), which presents that better project definition increases its reliability.

Chapter 3 contributes to the EVMS body of knowledge by providing a rich literature review on EVMS and analyzing experts' inputs regarding EVMS implementation and execution practice. This chapter analyzed 395 pieces of literature and performed an industry survey from 294 EVMS experts to find a gap between academia and industry. The study results found a gap between research projects and industry needs to improve the implementation and execution of EVMS. Most of the research focused on accurate prediction, but the industry expected a better operation environment to improve the reliable application of EVMS. This research lays the groundwork for the EVMS Maturity and Environment Total Rating (METR) that will be applied to evaluate the EVM systems for government projects and programs.

The contribution of Chapter 4 is, for the first time, quantitatively measuring long-term performance impacts of APDM. The chapter quantifies and presents a significant relationship between project delivery methods and long-term pavement performance using the international roughness index (IRI). The work reveals that DB provides a statistically significant superior performance when compared to DBB on asphalt concrete pavement (ACP) resurfacing projects, on the order of 16 in/mile. The approximate monetary impact of the finding is estimated on the order of $100 billion in maintenance costs on the U.S. national highway system (NHS) over a 45-year lifecycle.

The contribution of Chapter 5 is building on the existing CE model by identifying opportunities for using CE in the built environment. This study identifies three stakeholders in the recycling value stream and estimates the monetary benefits of recycling C&D debris for each of them. The results show that waste generators can make $6.5 billion by recycling C&D waste currently sent to landfills; recyclers can generate about 10 percent profit, and end-user benefits are estimated at around $34 billion.

Table 6.1 Summary of Contributions and Impact

Phases	Contributions	Impact
Use of Front End Planning Data	• Developing PDRI MATRS version 5, which can assess FEP Maturity and Accuracy for large industrial projects	• 24% cost growth improvement for large industrial projects • Cost range from 47% to 18%
Use of Project Control Data	• Analyzing the literature and current practice of EVMS implementation to improve data reliability	• Pending until measuring the performance of the newly developed tool
Use of O&M Data	• Quantifying the impact of project delivery methods on pavement long-term performance	• $4.7 billion/year for the US National Highway System
Use of End of Life Data	• Quantifying the impact of Circular Economy applied to the U.S. construction industry	• Waste Generator: $8 billion savings • Recycler: 10 precent operation profit • End-users: $34 billion savings • U.S. total: 30 percent market increasement

The appropriate utilization of industry data can be achievable with clear objectives and upfront planning. Measuring the impact of the research according to the KMb theory illustrates the value of the work to the public and to practitioners. This dissertation follows the KMb practice and gauges the practical and financial impact of each chapter.

6.3 Research Limitations and Recommendations for Future Work

The result of each chapter may be limited to the collected data sample in said chapter. Chapter 2 data is collected from projects globally; however, 32 projects cannot be representative of all large industrial projects in the world. Similarly, the data used for Chapter 3 was collected from six states in the U.S., including 26 total projects. The findings are statistically significant, and the projects were meticulously selected; but they still may not be representative of all pavement projects. This said, the author and research teams went to great length to design research studies that would contribute to both the body of knowledge and practice.

The future study recommended improving sustainable built environment planning and management. Although the infrastructure construction projects have already implemented aggressive recycling strategies in terms of material management, Chapter 5 of this dissertation identifies opportunities to enhance its efficiency during its life cycle, particularly during the planning and construction phases. Promoting the action of sustainable planning and design from the industry side using CE is expected to bring a significant impact on the C&D industry. Three further studies support this promotion.

First, a study is required to examine the effect of integrated delivery characteristics on various lifecycle performance metrics, considering both the engineering and management performance of infrastructure and building. For example, the Long-Term Pavement Performance (LTPP) database for pavement engineering does not include management information, so it limits the ability to link the database to construction project performance measurement. Chapter 4 of this dissertation provides an initial metric that can correlate pavement engineering and management performance through the International Roughness Index (IRI) and project delivery methods. This study should be extended to diverse applications such as underground facilities and buildings.

Second, a further study is suggested, which is related to various life cycle performance metrics to economic and sustainable built environment using the life cycle assessment (LCA). Kim et al. (2017) present the data-driven method to measure the environmental impact during the planning phase. This analysis should be expanded to all other facilities such as pavement and tunnels, and combined with economic analysis to transfer environmental impact to a manageable unit, cost. The assessment of the economic impact of sustainable building C&D market with CE can promote the sufficient participation of people who are involved in the recycling stream.

Finally, a comprehensive tool based on the PDRI for sustainable built environment planning and management should be developed. This dissertation presents the development of PDRI MATRS in Chapter 2 and applies the PDRI assessment system to assess EVMS performance in Chapter 3. A similar type of assessment tool for a sustainable built environment provides tangible measures that can maximize the impact on the industry.

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APPENDIX A

PDRI MATRITY SCORE SHEETS

Unweighted PDRI Score Sheet

Note: Bolded Elements are included in the FEED maturity score.
An Excel™ version of this matrix accompanies with Construction Industry Institute.

SECTION I - BASIS OF PROJECT DECISION							
CATEGORY	**Definition Level**						
Element	**0**	**1**	**2**	**3**	**4**	**5**	**Score**
A. MANUFACTURING OBJECTIVES CRITERIA							
A1. Reliability Philosophy							
A2. Maintenance Philosophy							
A3. Operating Philosophy							
CATEGORY A TOTAL							
B. BUSINESS OBJECTIVES							
B1. Products							
B2. Market Strategy							
B3. Project Strategy							
B4. Affordability/Feasibility							
B5. Capacities							
B6. Future Expansion Considerations							
B7. Expected Project Life Cycle							
B8. Social Issues							
CATEGORY B TOTAL							
C. BASIC DATA RESEARCH & DEVELOPMENT							
C1. Technology							
C2. Processes							
CATEGORY C TOTAL							
D. PROJECT SCOPE							
D1. Project Objectives Statement							
D2. Project Design Criteria							
D3. Site Characteristics Available vs. Req'd							
D4. Dismantling and Demolition Req'mts							
D5. Lead/Discipline Scope of Work							
D6. Project Schedule							
CATEGORY D TOTAL							
E. VALUE ENGINEERING							
E1. Process Simplification							
E2. Design & Material Alts. Considered/Rejected							
E3. Design For Constructability Analysis							
CATEGORY E TOTAL							
Section I Total							

Definition Levels

0 = Not Applicable
1 = Complete Definition
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

SECTION II - BASIS OF DESIGN							
CATEGORY Element	**Definition Level**						**Score**
	0	**1**	**2**	**3**	**4**	**5**	
F. SITE INFORMATION							
F1. Site Location							
F2. Surveys & Soil Tests							
F3. Environmental Assessment							
F4. Permit Requirements							
F5. Utility Sources with Supply Conditions							
F6. Fire Protection & Safety Considerations							
CATEGORY F TOTAL							
G. PROCESS / MECHANICAL							
G1. Process Flow Sheets							
G2. Heat & Material Balances							
G3. Piping & Instrumentation Diagrams (P&ID's)							
G4. Process Safety Management (PSM)							
G5. Utility Flow Diagrams							
G6. Specifications							
G7. Piping System Requirements							
G8. Plot Plan							
G9. Mechanical Equipment List							
G10. Line List							
G11. Tie-in List							
G12. Piping Specialty Items List							
G13. Instrument Index							
CATEGORY G TOTAL							
H. EQUIPMENT SCOPE							
H1. Equipment Status							
H2. Equipment Location Drawings							
H3. Equipment Utility Requirements							
CATEGORY H TOTAL							
I. CIVIL, STRUCTURAL, & ARCHITECTURAL							
I1. Civil/Structural Requirements							
I2. Architectural Requirements							
CATEGORY I TOTAL							
J. INFRASTRUCTURE							
J1. Water Treatment Requirements							
J2. Loading/Unloading/Storage Facilities Req'mts							
J3. Transportation Requirements							
CATEGORY J TOTAL							

SECTION II - BASIS OF DESIGN (continued...)							
CATEGORY	Definition Level						Score
Element	0	1	2	3	4	5	
K. INSTRUMENT & ELECTRICAL							
K1. Control Philosophy							
K2. Logic Diagrams							
K3. Electrical Area Classifications							
K4. Substation Req'mts Power Sources Ident.							
K5. Electric Single Line Diagrams							
K6. Instrument & Electrical Specifications							
CATEGORY K TOTAL							
Section II Total							

Definition Levels

0 = Not Applicable
1 = Complete Definition
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

SECTION III - EXECUTION APPROACH							
CATEGORY	Definition Level						Score
Element	0	1	2	3	4	5	
L. PROCUREMENT STRATEGY							
L1. Identify Long Lead/Critical Equip. & Mat'ls							
L2. Procurement Procedures and Plans							
L3. Procurement Responsibility Matrix							
CATEGORY L TOTAL							
M. DELIVERABLES							
M1. CADD/Model Requirements							
M2. Deliverables Defined							
M3. Distribution Matrix							
CATEGORY M TOTAL							
N. PROJECT CONTROL							
N1. Project Control Requirements							
N2. Project Accounting Requirements							
N3. Risk Analysis							
CATEGORY N TOTAL							

SECTION III - EXECUTION APPROACH (continued...)							
CATEGORY	Definition Level						Score
Element	0	1	2	3	4	5	
P. PROJECT EXECUTION PLAN							
P1. Owner Approval Requirements							
P2. Engineering/Construction Plan & Approach							
P3. Shut Down/Turn-Around Requirements							
P4. Pre-Commiss. Turnover Sequence Req'mts							
P5. Startup Requirements							
P6. Training Requirements							
CATEGORY PTOTAL							
Section III Total							

Definition Levels

0 = Not Applicable
1 = Complete Definition
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

Weighted PDRI Score Sheet

Note: Bolded Elements are included in the FEED maturity score.
An Excel™ version of this matrix accompanies with Construction Industry Institute.

SECTION I - BASIS OF PROJECT DECISION							
CATEGORY	Definition Level						
Element	0	1	2	3	4	5	Score
A. MANUFACTURING OBJECTIVES CRITERIA							
A1. Reliability Philosophy	**0**	**1**	**5**	**9**	**14**	**20**	
A2. Maintenance Philosophy	**0**	**1**	**3**	**5**	**7**	**9**	
A3. Operating Philosophy	**0**	**1**	**4**	**7**	**12**	**16**	
CATEGORY A TOTAL							
B. BUSINESS OBJECTIVES							
B1. Products	**0**	**1**	**11**	**22**	**33**	**56**	
B2. Market Strategy	0	2	5	10	16	26	
B3. Project Strategy	0	1	5	9	14	23	
B4. Affordability/Feasibility	0	1	3	6	9	16	
B5. Capacities	**0**	**2**	**11**	**21**	**33**	**55**	
B6. Future Expansion Considerations	**0**	**2**	**3**	**6**	**10**	**17**	
B7. Expected Project Life Cycle	**0**	**1**	**2**	**3**	**5**	**8**	
B8. Social Issues	0	1	2	5	7	12	
CATEGORY B TOTAL							
C. BASIC DATA RESEARCH & DEVELOPMENT							
C1. Technology	**0**	**2**	**10**	**21**	**39**	**54**	
C2. Processes	**0**	**2**	**8**	**17**	**28**	**40**	
CATEGORY C TOTAL							
D. PROJECT SCOPE							
D1. Project Objectives Statement	0	2	8	14	19	25	
D2. Project Design Criteria	**0**	**2**	**6**	**11**	**16**	**22**	
D3. Site Characteristics Available vs. Req'd	**0**	**2**	**9**	**16**	**22**	**29**	
D4. Dismantling and Demolition Req'mts	**0**	**2**	**5**	**8**	**12**	**15**	
D5. Lead/Discipline Scope of Work	0	1	4	7	10	13	
D6. Project Schedule	0	2	6	9	13	16	
CATEGORY D TOTAL							
E. VALUE ENGINEERING							
E1. Process Simplification	0	0	2	4	6	8	
E2. Design & Material Alts. Considered/Rejected	0	0	2	4	5	7	
E3. Design For Constructability Analysis	0	0	3	5	8	12	
CATEGORY E TOTAL							
Section I Total							

Definition Levels

0 = Not Applicable
1 = Complete Definition
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete or Poor Definition

SECTION II - BASIS OF DESIGN							
CATEGORY	Definition Level						
Element	**0**	**1**	**2**	**3**	**4**	**5**	**Score**
F. SITE INFORMATION							
F1. Site Location	0	2	10	18	26	32	
F2. Surveys & Soil Tests	**0**	**1**	**4**	**7**	**10**	**13**	
F3. Environmental Assessment	**0**	**2**	**5**	**10**	**15**	**21**	
F4. Permit Requirements	**0**	**1**	**3**	**5**	**9**	**12**	
F5. Utility Sources with Supply Conditions	**0**	**1**	**4**	**8**	**12**	**18**	
F6. Fire Protection & Safety Considerations	**0**	**1**	**2**	**4**	**5**	**8**	
CATEGORY F TOTAL							
G. PROCESS / MECHANICAL							
G1. Process Flow Sheets	**0**	**2**	**8**	**17**	**26**	**36**	
G2. Heat & Material Balances	**0**	**1**	**5**	**10**	**17**	**23**	
G3. Piping & Instrumentation Diagrams (P&ID's)	**0**	**2**	**8**	**15**	**23**	**31**	
G4. Process Safety Management (PSM)	**0**	**1**	**2**	**4**	**6**	**8**	
G5. Utility Flow Diagrams	**0**	**1**	**3**	**6**	**9**	**12**	
G6. Specifications	**0**	**1**	**4**	**8**	**12**	**17**	
G7. Piping System Requirements	**0**	**1**	**2**	**4**	**6**	**8**	
G8. Plot Plan	**0**	**1**	**4**	**8**	**13**	**17**	
G9. Mechanical Equipment List	**0**	**1**	**4**	**9**	**13**	**18**	
G10. Line List	**0**	**1**	**2**	**4**	**6**	**8**	
G11. Tie-in List	**0**	**1**	**2**	**3**	**4**	**6**	
G12. Piping Specialty Items List	**0**	**1**	**1**	**2**	**3**	**4**	
G13. Instrument Index	**0**	**1**	**2**	**4**	**5**	**8**	
CATEGORY G TOTAL							
H. EQUIPMENT SCOPE							
H1. Equipment Status	**0**	**1**	**4**	**8**	**12**	**16**	
H2. Equipment Location Drawings	**0**	**1**	**2**	**5**	**7**	**10**	
H3. Equipment Utility Requirements	**0**	**1**	**2**	**3**	**5**	**7**	
CATEGORY H TOTAL							
I. CIVIL, STRUCTURAL, & ARCHITECTURAL							
I1. Civil/Structural Requirements	**0**	**1**	**3**	**6**	**9**	**12**	
I2. Architectural Requirements	**0**	**1**	**2**	**4**	**5**	**7**	
CATEGORY I TOTAL							
J. INFRASTRUCTURE							
J1. Water Treatment Requirements	**0**	**1**	**3**	**5**	**7**	**10**	
J2. Loading/Unloading/Storage Facilities Req'mts	**0**	**1**	**3**	**5**	**7**	**10**	
J3. Transportation Requirements	**0**	**1**	**2**	**3**	**4**	**5**	
CATEGORY J TOTAL							

SECTION II - BASIS OF DESIGN (continued...)							
CATEGORY	**Definition Level**						**Score**
Element	**0**	**1**	**2**	**3**	**4**	**5**	
K. INSTRUMENT & ELECTRICAL							
K1. Control Philosophy	**0**	**1**	**3**	**5**	**7**	**10**	
K2. Logic Diagrams	**0**	**1**	**2**	**3**	**3**	**4**	
K3. Electrical Area Classifications	**0**	**0**	**2**	**4**	**7**	**9**	
K4. Substation Req'mts Power Sources Ident.	**0**	**1**	**3**	**5**	**7**	**9**	
K5. Electric Single Line Diagrams	**0**	**1**	**2**	**4**	**6**	**8**	
K6. Instrument & Electrical Specifications	**0**	**1**	**2**	**3**	**5**	**6**	
CATEGORY K TOTAL							
Section II Total							

Definition Levels

0 = Not Applicable — 2 = Minor Deficiencies — 4 = Major Deficiencies
1 = Complete Definition — 3 = Some Deficiencies — 5 = Incomplete or Poor Definition

SECTION III - EXECUTION APPROACH							
CATEGORY	**Definition Level**						**Score**
Element	**0**	**1**	**2**	**3**	**4**	**5**	
L. PROCUREMENT STRATEGY							
L1. Identify Long Lead/Critical Equip. & Mat'ls	0	1	2	4	6	8	
L2. Procurement Procedures and Plans	0	0	1	2	4	5	
L3. Procurement Responsibility Matrix	0	0	1	2	2	3	
CATEGORY L TOTAL							
M. DELIVERABLES							
M1. CADD/Model Requirements	0	0	1	1	2	4	
M2. Deliverables Defined	0	0	1	2	3	4	
M3. Distribution Matrix	0	0	0	1	1	1	
CATEGORY M TOTAL							
N. PROJECT CONTROL							
N1. Project Control Requirements	0	0	2	4	6	8	
N2. Project Accounting Requirements	0	0	1	2	2	4	
N3. Risk Analysis	0	1	2	3	4	5	
CATEGORY N TOTAL							

SECTION III - EXECUTION APPROACH (continued...)							
CATEGORY Element	Definition Level						Score
	0	**1**	**2**	**3**	**4**	**5**	
P. PROJECT EXECUTION PLAN							
P1. Owner Approval Requirements	0	0	2	3	5	6	
P2. Engineering/Construction Plan & Approach	0	1	3	5	8	11	
P3. Shut Down/Turn-Around Requirements	0	1	3	4	6	7	
P4. Pre-Commiss. Turnover Sequence Req'mts	**0**	**1**	**1**	**2**	**4**	**5**	
P5. Startup Requirements	**0**	**0**	**1**	**2**	**3**	**4**	
P6. Training Requirements	0	0	1	1	2	3	
CATEGORY PTOTAL							
Section III Total							

Definition Levels

0 = Not Applicable 2 = Minor Deficiencies 4 = Major Deficiencies
1 = Complete Definition 3 = Some Deficiencies 5 = Incomplete or Poor Definition

FEED Maturity Score Normalization Formula: The following formula converts the raw maturity score into an index between 0 and 100, with 100 having the highest possible maturity. Note: The normalization process flips the usual PDRI scoring where "lower is better," to create a new maturity index where higher is better.

$$Normalized\ Maturity\ Score = (-0.1456 * FEED\ Raw\ Maturity\ Total\ Score) + 107.86$$

APPENDIX B

PDRI MATURITY ELEMENT DESCRIPTIONS

The following maturity element descriptions help generate a clear understanding of the terms used in the project score sheet. Some descriptions include checklists of sub-elements. These sub-elements clarify concepts and facilitate ideas, to make the assessment of each element easier. Note that these checklists are not all-inclusive and that the user may supplement them when necessary; in some cases sub-element items in the checklists are not applicable, so the user should just ignore them.

The descriptions follow the order in which they are presented in the project score sheet; they are organized in a hierarchy by section, category, and then element. The score sheet consists of three main sections, each of which contains a series of categories broken down into elements. Note that some of the elements have issues listed that are specific to projects that are renovations and revamps or part of a repetitive program. Identified as "Additional items to consider for renovation & revamp projects" these issues should be used for discussion if applicable. Users generate the score of each element by evaluating its definition level.

It should be noted that PDRI MATRS was developed to evaluate large industrial projects with value of greater than $10 million. The sections, categories, and elements are organized as discussed below.

SECTION I: BASIS OF PROJECT DECISION

This section consists of information necessary for understanding the project objectives. The completeness of this section indicates whether the project team is aligned enough to fulfill the project's business objectives and drivers during FEP.

Categories:

A – Manufacturing Objectives Criteria
B – Business Objectives
C – Basic Data Research & Development
D – Project Scope
E – Value Engineering

SECTION II: BASIS OF DESIGN

This section addresses processes and technical information elements that should be evaluated for a full understanding of the engineering/design requirements necessary for the project.

Categories:

F – Site Information
G – Process / Mechanical
H – Equipment Scope
I – Civil, Structural, & Architectural
J – Infrastructure
K – Instrument & Electrical

SECTION III: EXECUTION APPROACH

This section consists of elements that should be evaluated for a full understanding of the owner's strategy and required approach for executing the project construction and closeout.

Categories:

L – Procurement Strategy
M – Deliverables
N – Project Control
P – Project Execution Plan

The following pages contain detailed descriptions for each element in the maturity matrix:

SECTION I: BASIS OF PROJECT DECISION

This section consists of information necessary for understanding the project objectives. The completeness of this section indicates whether the project team is aligned enough to fulfill the project's business objectives and drivers during FEP.

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
A. MANUFACTURING OBJECTIVES CRITERIA	**0**	**1**	**2**	**3**	**4**	**5**
A1. Reliability Philosophy A list of the general design principles to be considered to achieve dependable operating performance from the unit/facility or upgrades instituted for this project. Evaluation criteria should include: ☐ Justification of spare equipment ☐ Control, alarm, security and safety systems redundancy, and access control ☐ Extent of providing surge and intermediate storage capacity to permit independent shutdown of portions of the plant ☐ Mechanical/structural integrity of components (metallurgy, seals, types of couplings, bearing selection) ☐ Identify critical equipment and measures to be taken to prevent loss due to sabotage or natural disaster ☐ Other *Comments on Issues:* *Reliability models and simulations are typically used to validate on-line plant time.*	**Not required for project.**	**The reliability philosophy for this project has been documented and approved by key stakeholders (e.g., maintenance, operations, corporate reliability group) as a basis for detailed design.** The reliability philosophy aligns with organizational guidelines and specifications, if available. It includes justification for spare equipment, redundancy and access control for safety systems. It also includes surge and storage system requirements to support shutdowns, mechanical/structural integrity and critical equipment requirements as applicable.	**Most of the philosophy around reliability has been documented and is under review, but not fully approved.** A few issues such as, seals, couplings, and spare justification are not complete. These issues will need to be addressed in the detailed design phase.	**Some of the design principles for reliability have been developed.** Issues such as metallurgy, safety system redundancy, and bearing selection have not been determined or documented. These and other issues will need to be resolved before moving into detailed design.	**The applicable reliability guidelines and guidance have been identified.** Some initial thoughts have been applied to this effort; however, this information has not been applied to the project. Little or no meeting time or design hours have been expended on this topic and nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Potential impacts to existing operations		The potential impacts to existing operations have been identified and mitigation measures have been approved.	The potential impacts to existing operations have been documented and are under review.	Some of the potential impacts to existing operations have been documented.	The potential impacts to existing operations have been identified.	

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
A. MANUFACTURING OBJECTIVES CRITERIA	**0**	**1**	**2**	**3**	**4**	**5**
A2. Maintenance Philosophy A list of the general design principles to be considered to meet unit/facility (or upgrades instituted for this project) has been developed to maintain operations at a prescribed level. Evaluation criteria includes: ☐ Scheduled unit/equipment shutdown frequencies and durations ☐ Equipment access/monorails/cranes/other lifting equipment ☐ Maximum weight or size requirements for available repair equipment ☐ Equipment monitoring requirements (e.g., vibrations monitoring) ☐ Other *Comments on Issues:* *Other items typically include: repairs inside or outside the plant and the time and transportation effort for those activities. Additionally, reliability models and simulations are typically used to validate on-line plant time.*	**Not required for project.**	**The maintenance philosophy for this project has been documented and approved by key stakeholders (e.g., maintenance, operations, owner representative, and facility management) as a basis for detailed design.** The maintenance philosophy aligns with organizational guidelines and specifications, if available. It includes scheduled unit/equipment shutdown frequencies and durations, maximum weight or size requirements for available repair equipment and equipment monitoring requirements.	**Most of the design principles for the maintenance philosophy have been developed and are under review, but not fully approved.** The maintenance philosophy is under review. A few issues such as monitoring for selected pieces of equipment and equipment maintenance access have not been completely defined.	**Some design principles for the maintenance philosophy have been developed.** Issues such as equipment shutdown frequencies and mechanical equipment maintenance access for some portions of the facility have not been determined.	**The maintenance philosophy requirements have been identified.** Some initial thoughts have been applied to this effort. Little or no meeting time or design hours have been expended on this topic and little has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Maintenance impact of renovation projects ☐ Common/ spare parts (repair vs. replace existing components) ☐ Interruptions to existing and adjacent facilities during R&R work ☐ Compatibility of maintenance philosophy for new systems and equipment with existing use and maintenance philosophy ☐ Coordination of the project with any maintenance projects ☐ Tie-in points and interface with existing unit fully identified		The maintenance impact, spare parts, interruptions to facilities, compatibility with existing use, coordination with maintenance projects, tie-in points and interface with existing facilities have been documented and approved.	Most of the maintenance impacts, spare parts, interruptions to facilities, compatibility with existing use, coordination with maintenance projects, tie-in points, and interface with existing facilities, have been documented and are under review, but not fully approved.	Some of the maintenance impacts, spare parts, and interruptions to facilities, compatibility with existing use, and coordination with maintenance projects, tie-in points, and interface with existing facilities have been documented.	The maintenance impact, spare parts, interruptions to facilities, compatibility with existing use, coordination with maintenance projects, tie-in points, and interface with existing facilities have been identified.	

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	**BEST**		**MEDIUM**		**WORST**
A. MANUFACTURING OBJECTIVES CRITERIA	**0**	**1**	**2**	**3**	**4**	**5**
A3. Operating Philosophy A list of the general design principles that need to be considered to achieve the projected overall performance requirements (such as on-stream time or service factor) for the unit/facility or upgrade. Evaluation criteria should include: ☐ Level of operator coverage and automatic control to be provided ☐ Operating time sequence (ranging from continuous operation to five day, day shift only) ☐ Necessary level of segregation and clean out between batches or runs ☐ Desired unit turndown capability ☐ Design requirements for routine startup and shutdown ☐ Design to provide security protection for material management and product control ☐ Other *Comments on Issues:* *Other items typically include: a process hazard analysis (PHA) study is planned to assure safety operation*	**Not required for project.**	**The operating philosophy for this project has been documented and approved by key stakeholders (e.g., maintenance, operations, owner representative, and facility management) as a basis for detailed design.** The operating philosophy aligns with organizational guidelines and specifications, if available. It includes level of operator coverage and automatic control operating time sequence, necessary level of segregation and clean out between batches or runs, desired unit turndown capability, design requirements for routine startup and shutdown, design to provide security protection for material management and product control.	**Most design principles for the operating philosophy have been documented and are under review, but not fully approved.** The operating philosophy is under review. A few issues such as operating time sequence and routine start up / shutdown requirements have not been completely defined.	**Some design principles for the operating philosophy have been documented.** Operating design principles such as the level of operator coverage, automatic controls, and security protection, have yet to be developed.	**The applicable operating design principles have been identified.** Some initial thoughts have been applied to this effort. Little meeting time or design hours have been expended on this topic and little has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
B. BUSINESS OBJECTIVES	**0**	**1**	**2**	**3**	**4**	**5**
B1. Products A list of product(s) to be manufactured and/or the specifications and tolerances that the project is intended to deliver. It should address items such as: □ Chemical composition □ Physical form/properties □ Raw materials □ Packaging □ Intermediate/final product form □ Allowable impurities □ By-products □ Wastes □ Hazards associated with products □ Other For projects that do not apply directly to products (e.g., instrument upgrade, environmental improvements, structural integrity, regulatory compliance, infrastructure improvement, etc.), this element should be considered not applicable. *Comments on Issues:* *The list of product(s) typically also includes:* □ Products produced at the unit; □ Products coming from a third party company; □ Products distance and time to be available at the plant *Additionally, the list of product(s) typically considers integration with other ongoing projects or existing facilities, if any.*	**Not required for project.**	**All products for this project have been documented and approved by key stakeholders (e.g., marketing department, maintenance, operations, owner representative, and facility management) as a basis for detailed design.** The products align with organizational guidelines and specifications, if available. For each product this includes chemical composition, physical form/properties, raw materials, packaging, intermediate/final product form, allowable impurities, by-products, wastes, and hazards.	**Most product design and manufacturing specifications have been documented and are under review, but not yet approved.** A few issues such as specifications and tolerances for selected products have not been completely defined.	**Some product design and manufacturing specifications have not been developed.** Issues such as by-products, allowable impurities, and wastes are yet to be defined.	**The applicable product design and manufacturing specifications have been identified.** Some initial thoughts have been applied to this effort. Little or no meeting time or design hours have been expended on this topic and little has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST	MEDIUM			WORST
B. BUSINESS OBJECTIVES	**0**	**1**	**2**	**3**	**4**	**5**
B2. Market Strategy A market strategy has been developed and clearly communicated. It identifies the driving forces (other than safety) for the project and specifies what is most important from the viewpoint of the business group. It should address items such as: ☐ Cost ☐ Maximum project cost that market will accept ☐ Production cost ☐ Cost reduction over time ☐ Schedule ☐ Product demand schedule (over operational life) ☐ First product sales date ☐ Quality, including critical product specifications ☐ Other *Comments on Issues:* *Other issues can include business benefits such as the internal rate of return (IRR), the return on revenue (ROR), net present value (NPV), subsidies, tax credits, competitive analysis, and regulatory requirements such as zero liquid discharge (ZLD), waste disposal and emissions. Social, political and economic issues, and in some cases safety concerns, should also be considered as part of the completeness of this element. For nonprofit and government agencies, this is a mission need statement to fill a capability gap. The key focus here is the driver for the project (i.e., cost, schedule, or quality)*	**Not required for project.**	**The market strategy has been documented and approved by key stakeholders (e.g., marketing department, owner representatives, maintenance, operations, and facility management) for inclusion into the capital appropriation request.** The market strategy is reviewed/updated and approved by the key stakeholders and aligns with organizational guidelines and specifications, if applicable. The market strategy includes funding level, project economics, sales, pricing forecasts, product launch schedule and risk analysis document.	**Most of the market strategy has been documented and is under review, but not fully approved.** The market strategy may have minor issues that require resolution such as the product demand schedule, initial project economics, sales, pricing forecasts or launch schedule. The strategy, for instance, should include a vision of future market share, critical raw materials costs and origin (imported or not), and whether it is a new or an upgraded product.	**Some of the market strategy has been developed with open items.** The market strategy has several issues that require resolution such as verification of earlier forecasted demand, the first product sales date and critical product specifications.	**Some items included in the market strategy have been identified.** Initial thoughts have been applied to identifying items in the market strategy; however, the strategy is not updated to the current requirements and no efforts have been applied to the project. Little or no meeting time or development hours have been expended on finalizing the market strategy and nothing has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
B. BUSINESS OBJECTIVES	**0**	**1**	**2**	**3**	**4**	**5**
B3. Project Strategy The project strategy has been defined. This strategy supports the market and/or business strategy or drivers. Address the priorities among the following items: ☐ Cost ☐ Schedule ☐ Quality ☐ Environmental Sustainability ☐ Security ☐ Other *Comments on Issues:* *The project strategy including specific customer requirements should be considered as part of the completeness of this element. Requirements for cost and schedule level of estimate and QA/QC requirements among others (e.g., safety requirements) should be established. Construction activities are planned in accordance with the project strategy. For a non-market driven project (i.e. security, environmental, safety, facility structure or equipment replacement, reliability) the project strategy should be aligned with the specific driver.*	**Not required for project.**	**The project strategy has been documented and approved by key stakeholders (e.g., the business unit) as a basis for detailed design.** The project strategy and priorities are consistent with respect to business drivers and market strategy, including cost, schedule, product quality, safety, health , environmental, sustainability, security, reliability and others.	**Most of the project strategy has been documented and is under review, but not fully approved.** The project strategy is consistent with the market strategy with respect to cost, schedule, quality, etc. The project strategy may have minor issues that require resolution.	**Some of the project strategy has been developed with open items.** The project strategy has several issues that require resolution such as cost, schedule or quality issues or other issues that are critical to the project strategy.	**Some items included in the project strategy have been identified.** Initial thoughts have been applied to identifying the project strategy; however, it has not been applied to the project. Little or no meeting time or development hours have been expended on the project strategy and nothing has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
B. BUSINESS OBJECTIVES	**0**	**1**	**2**	**3**	**4**	**5**
B4. Affordability/Feasibility Items that may improve the affordability of the project should be considered during scope development and communicated to the project team. These items may include incremental cost criteria such as: □ Consideration of feedstock availability and transport to the job site □ Understanding of raw material or feedstock and product variability in relation to cost and volume □ Reduction in manufacturing costs □ Performing an analysis of capital and operating cost versus sales and profitability □ Long-term environmental sustainability considerations □ Other *Comments on Issues:* *While this element references the project in the first sentence above, it is ultimately related to the affordability of the product over the facility's lifecycle. It also relates to the feasibility of delivering the product within specific cost, time, and other needs or constraints. Input on cost reduction options has been obtained from contractors and vendors (e.g., power supply, raw material availability and cost, equipment efficiency).*	**Not required for project.**	**Items that may improve the affordability/feasibility of the products have been completed and key stakeholders (e.g., the business unit) have approved the recommendations that will benefit the project.** Efforts to assess and improve the affordability/feasibility of the products being produced by the facility have been accepted, incorporated into the design, and have been taken into consideration during the development of the phase 3 budget estimate. Specific items such as feedstock availability, feed/product prices and transport logistics have been thoroughly vetted, including contingency plans.	**Most of the items that may improve the affordability/feasibility of the products have been documented and are under review, but not fully approved.** Efforts to assess and improve the affordability/feasibility of the products being produced by the facility have minor issues that require resolution, such as, getting input from a few contractors and vendors who are involved in the analysis.	**Some items that may improve the affordability/ feasibility of the products have been developed with open items.** Efforts to assess and improve the affordability/feasibility of the products being produced by the facility have several issues that require resolution, such as, getting input from key contractors and vendors who are involved in the analysis.	**Some items that may improve the affordability/feasibility of the products have been identified but not implemented.** Initial thoughts have been applied to this effort; however, affordability/feasibility items have not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
C. BUSINESS OBJECTIVES	**0**	**1**	**2**	**3**	**4**	**5**
B5. Capacities The design output or benefits to be gained from this project should be documented. Capacities are usually defined in terms of: ☐ On-stream factors ☐ Yield ☐ Design rate ☐ Increase in storage or throughput ☐ Regulatory driven requirements ☐ Product quality improvement ☐ Other *Comments on Issues:* *Other items typically include: storage inside the plant or outside storage areas close to the distribution centers, if necessary*	**Not required for project.**	**The capacities for this project have been documented and approved by key stakeholders (e.g., marketing department, engineering, maintenance, operations, owner representatives, and facility management) as a basis for detailed design.** The capacity aligns with organizational guidelines and specifications, if available. It addresses on-stream factors, yield, design rate, increase in storage or throughput, regulatory driven requirements, and product quality improvement.	**Most capacity design output issues have been documented and are under review, but not yet approved.** A few issues such as regulatory driven requirements or product quality improvement expectations have not been completely defined.	**Some capacity design output issues have been developed.** Items such as on-stream factors and design rate access for all portions of the facility are yet to be developed.	**Capacity design output and / or benefits have been identified.** Some initial thoughts have been applied to this effort. Little or no meeting time or design hours have been expended on this topic and little has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
B. BUSINESS OBJECTIVES	**0**	**1**	**2**	**3**	**4**	**5**
B6. Future Expansion Considerations A list of items to be considered in the unit design that will facilitate future expansion should be developed. Evaluation criteria may include: ☐ Providing space for future equipment or phased development ☐ Guidelines for over design of systems to allow for additions. For example, extra power, structure, storage, or control devices ☐ Guidelines for design that considers future expansion without compromising on-going operations, safety or security. For example, providing tie-ins for future expansion without necessitating a shutdown ☐ Environmental considerations and impacts ☐ Other *Comments on Issues:* *Other items typically include: availability of utilities such as water, steam, compressed air, etc. Future expansion could involve specific contracts with third-party companies.* *Construction knowledge and input are typically taken into account when considering the completeness of this element.* *Additionally, future expansion considerations can address how much structure and capacity is pre-invested for utilities, infrastructure expansion, etc.*	**Not required for project.**	**The future expansion considerations for this project have been documented and approved by key stakeholders (e.g., marketing department, maintenance, operations, owner representative, and facility management) as a basis for detailed design.** The considerations align with organizational guidelines and specifications, if available. They address providing space for future equipment or phased development, guidelines for over design of systems to allow for additions, guidelines for design that considers future expansion without compromising on-going operations, safety or security, and environmental considerations and impacts.	**Most of the future expansion considerations have been documented and are under review, but not yet approved.** A few issues such as environmental considerations and impacts have not been completely defined.	**Some of the future expansion considerations have been developed.** Issues such as guidelines for over design of systems to allow for additions and space for future equipment have not been addressed.	**Future expansion considerations have been identified.** Some initial thoughts have been applied to this effort. Little or no meeting time or design hours have been expended on this topic and little has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
B. BUSINESS OBJECTIVES	**0**	**1**	**2**	**3**	**4**	**5**
B7. Expected Project Life Cycle The time period that the facility is expected to be able to satisfy the products and capacities required should be documented. The life cycle will affect the selection of critical equipment, materials, and control devices. Requirements for ultimate disposal and dismantling should also be considered. Issues to consider may include: □ Operating life cycle (i.e., 10, 15, 20 years) □ Cost of ultimate dismantling and disposal □ Disposal of hazardous materials □ Possible future uses □ Environmental sustainability considerations □ Other *Comments on Issues:* *Other items typically include: time definition for the Return on Investments (RoI) for the project.* *Construction knowledge and input should be taken into account when considering the completeness of this element.*	**Not required for project.**	**The expected project life cycle have been documented and approved by appropriate stakeholders (e.g., marketing department, maintenance, operations, owner representative, and facility management) as a basis for detailed design.** The project life cycle aligns with organizational guidelines and specifications, if available. These include operating life cycle, cost of ultimate dismantling and disposal, disposal of hazardous materials, possible future uses, and environmental sustainability considerations.	**Most of the expected project life cycle considerations have been documented and are under review, but not yet approved.** A few issues such as possible future uses of the facility or sustainability considerations have not been completely defined.	**Some expected project life cycle considerations have been addressed.** Some items such as disposal of hazardous materials and dismantling costs considerations have not been addressed.	**The expected project life cycle principles have been identified.** Some initial thoughts have been applied to this effort. Little or no meeting time or design hours have been expended on this topic and little has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
B. BUSINESS OBJECTIVES	**0**	**1**	**2**	**3**	**4**	**5**
B8. Social Issues Identify and document any social issues, which if not addressed, could adversely impact the successful implementation of the project. These may include issues affecting the local or regional population. Evaluation of various social issues such as: ☐ Domestic culture vs. international culture ☐ Community relations ☐ Labor relations ☐ Government relations ☐ Education/training ☐ Safety and health considerations ☐ Environmental assessment/sustainability ☐ Other *Comments on Issues:* *Affected groups should be identified and engaged with a plan in place for design and construction. The impacts of social media on the proposed project have been addressed.*	**Not required for project.**	**The social issues plan has been documented and approved by key stakeholders (e.g., the business unit, public relations and legal counsel).** The social issues plan includes, but is not limited to; the way community and labor relations will be handled. Involved groups (e.g., the community, aboriginals/first nations, labor organizations, and governmental authorities) have been informed concerning the plan's major points and have a clear understanding and broad agreement with those plans. Outreach programs to educate the public about the project have been identified and documented, including safety and health considerations and environmental regulations. A budget has been established to address social issues.	**Most of the plan to address social issues has been documented and is under review, but not fully approved.** The social issues plan has minor issues that require resolution, such as specific community stakeholder groups identified, timing of public meetings and how labor relations will be handled. All Involved groups (e.g., the community, labor organizations, and governmental authorities) have not been fully informed concerning the plan's major points and do not yet have a clear understanding and broad agreement with the plan.	**Some of the plan has been developed to address social issues that may impact successful implementation of the project, with some open items.** The social issues plan has several issues that require resolution. These issues could include the way community relations and labor relations will be handled, etc. All involved groups (e.g., the community, labor organizations, and governmental authorities) have yet to be identified and/or the plan's major points have been preliminarily developed but not yet fully communicated.	**The social issues that may impact the project have been identified and are being investigated.** Initial thoughts have been applied to identifying social issues; however, the social issues plan has not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
C. BASIC DATA RESEARCH & DEVELOPMENT	**0**	**1**	**2**	**3**	**4**	**5**
C1. Technology The technology(ies) being used in this project to gain the desired results should be identified. Technologies may include chemical, biological, or mechanical processes, as well as information technology. Proven technology involves less risk than experimental technology to project cost or schedule. Issues to evaluate when assessing technologies include: ☐ Existing/proven or duplicate ☐ New ☐ Experimental ☐ Scale up from bench or pilot application to commercial scale ☐ Organization's experience with the technology ☐ Software development ☐ Other *Comments on Issues:* *Technology(ies) selection is the process of choosing the right mix of new or unproven technology, along with the application of existing technology to new or different uses, or the combination of existing and proven technology to achieve a specific goal.* *Other items typically include: main licensors requirements for the project, interfaces with licensors during design, construction, and start-up/commissioning, warranties, license fees, and control systems*	**Not required for project.**	**Technology planning studies for the chosen optimal technologies have been approved by key stakeholders (e.g., business unit, maintenance, and operations) as a basis for detailed design.** The technology choice was approved by the business unit, maintenance, and operations. The basis for technology selection has been documented and is based on reliable operational data for similar existing facilities. The technology selection process evaluated such factors as capital and operating cost, reliability, maintainability, process risk evaluation, environmental considerations, and technological obsolescence.	**Most technology planning studies to select the optimal technologies have been documented and are under review, but not yet approved.** The technology choice is in the process of being approved by the business unit, maintenance, and operations. The basis for technology selection has been documented and is based on either bench scale or pilot plant data for new technologies that verify initial assumptions relative to system or process performance or reliable operational data for similar existing facilities. The technology selection process evaluated such factors as capital and operating costs, reliability, maintainability, environmental considerations, process risk evaluation, and technological obsolescence.	**Some preliminary technology planning studies have been performed as a basis to select the optimal technologies.** The basis for technology selection utilizes either bench scale or pilot plant data for new technologies or reliable operational data for similar existing facilities. Additional information from one or both of these sources is required to complete the study. When the study is completed, it will be submitted to the sponsor, maintenance, and operations for review.	**Technology planning studies have been initiated to select the optimal technologies.** The basis for technology selection is utilizing either bench scale or pilot plant data for new technologies or reliable operational data from similar existing facilities. A majority of required information from one or both of these sources is needed to complete the study.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Integration of new technology with existing systems, including interface issues ☐ Safety systems potentially compromised by any new technology		The integration implications of new technology with existing systems, including safety, have been documented and approved.	The integration implications of new technology with existing systems, including safety, have been documented and are under review, but not yet approved.	The integration implications of new technology with existing systems, including safety, are known but have not been documented.	Little or no meeting time or design hours have been expended on this topic and little has been documented.	

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
C. BASIC DATA RESEARCH & DEVELOPMENT	**0**	**1**	**2**	**3**	**4**	**5**
C2. Processes A particular, specific sequence of steps to change the raw materials, intermediates, or sub-assemblies into the finished product or outcome. These process steps may involve conversion of an existing process stream into a new sequence of steps to meet facility requirements. Proven sequences of steps involve the least risk, while experimental processes have a potential for change or problems. Issues to evaluate include: ☐ Existing/proven or duplicate ☐ New ☐ Experimental ☐ Scale up from bench or pilot application to commercial scale ☐ Organization's experience with the process steps ☐ Other *Comments on Issues:* *Other items typically include: Availability of existing process engineering information to expedite the FEED phase*	**Not required for project.**	**Process selection studies have been documented and approved by key stakeholders as a basis for detailed design.** Process selection is based on reliable operational data from commercial scale production train in similar facilities. Proven acceptable ranges (PAR) have been defined for critical process steps. Capacity modeling, flow rates and energy usage calculations are complete and verified.	**Most process selection studies to select the optimal processes have been documented and are under review, but not yet approved.** Process selection is completed but not fully verified. Basis of process selection typically includes reliable operational data at commercial or pilot scale with scale up factors identified. Most PAR's are defined but final definition has yet to occur. Capacity modeling, flow rates and energy usage calculations are complete and verified.	**Process selection studies have been performed on a preliminary basis to select the optimal processes.** Process selection has been performed on a preliminary basis, but is not complete. The basis of process selection typically includes reliable operational data at commercial or pilot scale with scale up factors identified. Some PAR's defined but not yet finalized. Capacity modeling, flow rates and energy usage calculations are complete, but not verified.	**The required Process selection studies including guidelines/ guidance have been identified and some initial thoughts have been applied to this effort.** Process selection based on pilot scale studies is in progress with place holders for many critical steps. Few PARs are defined.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
D. PROJECT SCOPE	**0**	**1**	**2**	**3**	**4**	**5**
D1. Project Objectives Statement This statement defines the project objectives and priorities for meeting the business strategy. It should be clear, concise, measurable, and specific to the project. It is desirable to obtain total agreement from the entire project team regarding these objectives and priorities to ensure alignment. Specifically, the priorities among cost, schedule, and value-added quality features should be clear. To ensure the project is aligned to the applicable objectives, the following should be considered: ☐ Stakeholders' understanding of objectives, including questions or concerns ☐ Constraints or limitations placed on the project ☐ Typical objectives: ☐ Safety ☐ Quality ☐ Cost ☐ Schedule ☐ Technology usage ☐ Capacity or size ☐ Startup or commissioning ☐ Communication ☐ Operational performance ☐ Maintainability ☐ Security ☐ Sustainability ☐ Other *Comments on Issues:* *The project objectives statement translates business requirements into a set of measurable outcomes for the project. It is a key document to ensure that project participants are working towards the "same" project. Generally, the project objectives statement is contained in a document that lays out all objectives in one place. For many organizations, this document has a specific name (e.g., Project Requirements Document (PRD)); it is frequently part of the project charter or project premise document.*	**Not required for project.**	**The project objectives statement has been documented and approved by key stakeholders (e.g., the business unit, project management, operations and maintenance).** The project objectives statement has been communicated to all project participants and is well understood. The project objectives statement has been agreed to as the project's basis with regards to business case, project objectives, and priorities between project features (cost, schedule, quality, safety, etc.).	**Most of the project objectives statement is documented and under review, but not fully approved.** The project objectives statement has a few minor issues that require resolution such as those surrounding technology usage or security, etc. Key stakeholder groups have been engaged and not all objectives finalized.	**Some of the project objectives statement has been developed with open items.** The project objectives statement has several issues that require resolution such as those surrounding the priorities between project cost, schedule, and quality, capacity, maintainability, etc. Key stakeholder groups have not been fully engaged.	**Some items included in the project objectives statement have been identified.** Initial thoughts have been applied to identifying items in the project objectives statement; however, there are several missing items that are not developed. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
D. PROJECT SCOPE	**0**	**1**	**2**	**3**	**4**	**5**
D2. Project Design Criteria The requirements and guidelines which govern the design of the project should be developed. When performing repetitive projects for the same facility, these may be well understood. Evaluation criteria may include: □ Level of design detail required □ Climatic data □ Codes and standards: □ National □ Local □ Utilization of engineering standards: □ Owner's □ Mixed □ Contractor's □ Security standards/guidelines to be utilized □ Other *Comments on Issues:* *Other items typically include: specific country codes and standards related to safety and design requirements, specific codes and standards for each discipline: Civil, Structural, Mechanical, Piping & Instrumentation, Controls, Electrical, Process, etc.*	**Not required for project.**	**All project design criteria are defined and approved by key stakeholders as a basis for detailed design.** All design specifications that govern the design of the project are defined and selected forming a basis for detailed design. The design criteria have been approved by the project team, operations & maintenance. Safety design criteria and design safety factors are defined.	**Most project design criteria are documented and are under review, but not yet approved.** Design specifications and standards are essentially defined and selected for use. Some are in the process of being approved by the appropriate parties.	**Some project design criteria have been identified and are in the process of being documented.** Some design specifications and standards have been identified and are awaiting review.	**The list of required project design criteria has been identified and some initial thoughts have been applied to this effort.** Only a few design criteria have been identified. Little or no meeting time or design hours have been expended on this topic and little has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** □ Clearly define controlling specifications, especially where new codes and regulations will override older requirements □ Ensure that specifications support replacement of any obsolete systems or equipment.		Controlling specifications have been clearly defined, documented, and approved.	Controlling specifications have generally been defined and documented.	Controlling specifications have been identified for review.	Little or no meeting time or design hours have been expended on this topic and little has been documented.	

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
D. PROJECT SCOPE	**0**	**1**	**2**	**3**	**4**	**5**
D3. Site Characteristics Available vs. Required An assessment of the available versus the required site characteristics is needed. The intent is to ensure that the project team has taken into consideration the need to improve or upgrade existing site utilities and support characteristics. Issues to consider should include: ☐ Capacity: ☐ Utilities ☐ Fire water ☐ Flare systems ☐ Cooling water ☐ Power ☐ Pipe racks ☐ Waste treatment/ disposal ☐ Storm water containment system ☐ Type of buildings/ structures ☐ Land area ☐ Amenities: ☐ Food service ☐ Change rooms ☐ Medical facilities ☐ Recreation facilities ☐ Ambulatory access ☐ Product shipping facilities ☐ Material receiving facilities ☐ Material storage facilities ☐ Product storage facilities ☐ Security: ☐ Setbacks ☐ Sight lines ☐ Clear zones ☐ Access and egress ☐ Fencing, gates, and barriers ☐ Security lighting ☐ Sustainability considerations, including possible certification (for example, by the U.S. Green Building Council). ☐ Other *Comments on Issues:* *Construction knowledge and input are typically taken into account when considering the completeness of this element.*	**Not required for project.**	**Required site characteristics versus those available are fully defined and approved by key stakeholders as a basis for detailed design.** A report outlining the required site characteristics including those available and those required within the scope of the project has been written, reviewed by the key stakeholders and approved.	**Most required site characteristics versus those available are documented and under review, but not yet approved.** Most site utilities and support characteristics necessary for the project are well defined in terms of type, capacity, space requirements, amenities, logistics facilities, and security. A draft report has been issued.	**Some required site characteristics needed for the project are defined but those available are not fully identified.** Site utilities and support characteristics necessary for the project are defined in terms of type, capacity and so forth. However, the availability of required characteristics is not generally known.	**Required site characteristics are partially defined and those available are not identified.** General knowledge of existing characteristics is known, but no survey has been conducted. Moreover, little or no meeting time or design hours have been expended on this element.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Complete condition assessment of existing facilities and infrastructure ☐ As-Built accuracy and availability (update/verify as-built documentation prior to project initiation) ☐ Worksite availability and access for R&R activities ☐ Existing space available to occupants during renovation work ☐ Uncertainty of "as-found" conditions, especially related to: ☐ Structural integrity: steel or concrete loading ☐ Piping capacity/ integrity/ routing ☐ Condition of required isolation points Location, condition, and capacity of electrical systems components ☐ Investigation tools to assist in the documentation of existing conditions: ☐ Photographs / Video ☐ Remote inspection ☐ Laser scanning ☐ Infrared scanning ☐ Non-Destructive Testing ☐ Ground Penetrating Radar ☐ Ultrasonic Testing ☐ Other		Items related to R&R have been fully addressed and documented.	Items related to R&R have mostly been addressed.	Items related to R&R have been identified and are being assessed.	Little or no meeting time or design hours have been expended on R&R items.	

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
D. PROJECT SCOPE	**0**	**1**	**2**	**3**	**4**	**5**
D4. Dismantling and Demolition Requirements A scope of work has been defined and documented for the decommissioning and dismantling of existing equipment and/or piping which may be necessary for completing new construction. This scope of work should support an estimate for cost and schedule. Evaluation criteria should include: ☐ Timing/sequencing ☐ Permits ☐ Approval ☐ Safety requirements ☐ Hazardous operations and/or materials ☐ Plant/operations requirements ☐ Storage or disposal of dismantled equipment/materials ☐ Narrative (scope of work) for each system ☐ Environmental assessment ☐ Are the systems that will be decommissioned/dismantled: ☐ Named and marked on process flow diagrams ☐ Named and marked on P&IDs ☐ Denoted on line lists and equipment lists ☐ Denoted on piping plans or photo-drawings ☐ Other *Comments on Issues:* *Other items typically include: dismantling and demolition sequencing defined. Construction knowledge and input is typically taken into account when considering the completeness of this element.*	**Not required for project.**	**Dismantling and demolition requirements have been documented and approved by key stakeholders (e.g., maintenance, operations, construction) as a basis for detailed design.** Dismantling and demolition requirements have been identified and described in a complete scope of work document supporting a good estimate for cost and schedule.	**Most dismantling and demolition requirements have been documented and are under review, but not yet approved.** Dismantling and demolition requirements have been identified and described in a scope of work document. Most details including the physical limits, required permits and approvals, and health, safety, and environmental (HSE) requirements have been developed.	**Some of the dismantling and demolition requirements have been defined.** Dismantling and demolition deliverable details such as physical limits, required permits/approvals, and HSE requirements need to be developed. Execution timing, sequencing, and other details need to be defined before moving to detailed design.	**Dismantling and demolition requirements have been identified and some initial thoughts have been applied to this effort.** The details necessary to clarify the scope of work and to prepare a cost estimate and schedule are not available and there is no scope of work document available.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Use of photographs, video records, etc. in scope documents to ensure existing conditions clearly defined ☐ Physical identification of extent of demolition to clearly define limits ☐ Segregation of demolition activities from new construction, and operations (e.g., physical disconnect or "air gap") ☐ Establish decontamination and purge requirements to support dismantling		Items related to existing conditions, demolition activities and decontamination and purge requirements have been fully addressed and documented.	Items related to existing conditions, demolition activities and decontamination and purge requirements have mostly been addressed.	Items related to existing conditions, demolition activities and decontamination and purge requirements have been identified and are being assessed.	Little or no meeting time or design hours have been expended on defining existing conditions, demolition activities and decontamination and purge requirements.	

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	**BEST**		**MEDIUM**		**WORST**
E. PROJECT SCOPE	**0**	**1**	**2**	**3**	**4**	**5**
D5. Lead Discipline Scope of Work A complete narrative description of the project laying out the major components of work to be accomplished, generally discipline oriented, should be developed. This narrative should be tied to a high level Work Breakdown Structure (WBS) for the project. Items to consider would include: ☐ Sequencing of work ☐ Interface issues for various contractors, contracts, or work packages ☐ Other *Comments on Issues:* *For example, at the end of FEP stage 3, the WBS should support a +/- 10% cost estimate, or an Association for the Advancement of Cost Engineering International (AACEi) Class 3 cost estimate.*	**Not required for project.**	**A document describing the division of work scopes and responsibilities has been documented and approved by key stakeholders (e.g., the business unit, engineering, project management, operations and maintenance).** The division of work scopes and responsibilities is based on the project's work breakdown structure (WBS) established by the project team. This document has been approved by key stakeholders and is compatible with the project execution plan, estimate, schedule, and project control baselines.	**Most of the document describing the division of work scopes and responsibilities is documented and under review, but not fully approved.** The division of work scopes and responsibilities is based on the project's Work Breakdown Structure (WBS) established by the project team; however, it has minor issues that require resolution which may include the sequencing of work or other minor interface issues.	**Some of the document describing the division of work scopes and responsibilities has been developed with open items.** There are a number of issues around work scope divisions that need to be resolved and reflected in the Work Breakdown Structure (WBS). These issues may include coordination between key disciplines or other critical interface issues.	**Some items included in the division of work scopes have been identified, but has not been tied to a high level WBS.** Initial thoughts have been applied to identifying items in the division of work scopes; however, the division of work scopes and responsibilities have not yet been related to the project Work Breakdown Structure (WBS). Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Identification of specific interface or coordination efforts with operations and owner's staff		The lead discipline scope of work document has been documented and approved, including identification of specific interface or coordination efforts with operations and owner's staff.	Most of the R&R items related to the lead discipline scope of work document have been identified, documented and are under review.	Some of the R&R items related the lead discipline scope of work document have been identified, including interface or coordination efforts with operations and owner's staff.	Little or no meeting time or development hours have been expended on R&R items related to the lead discipline scope of work document.	

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<tr><th colspan="1">SECTION I – BASIS OF PROJECT DECISION</th><th colspan="6">Definition Level</th></tr>
<tr><th></th><th>N/A</th><th>BEST</th><th></th><th>MEDIUM</th><th></th><th>WORST</th></tr>
<tr><th>D. PROJECT SCOPE</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>D6. Project Schedule

A project milestone schedule should be developed, analyzed, and agreed upon by the major project participants. It should include milestones, unusual schedule considerations and appropriate master schedule contingency time (float), procurement of long-lead or critical pacing equipment, and required submissions and approvals. This schedule should involve obtaining early input from:

☐ Owner/Operations
☐ Design/Engineering
☐ Construction
☐ Procurement
☐ Other

Comments on Issues:
Some organizations do not consider float as a contingency; others do. For example, at the end of FEP stage 3, the schedule should support a +/- 10% cost estimate, or an Association for the Advancement of Cost Engineering International (AACEi) Class 3 cost estimate.</td><td rowspan="2">Not required for project.</td><td>The project schedule has been documented and approved by key stakeholders (e.g., the business unit, project team, engineering contractor and construction contractor). The project schedule serves as a basis for the cost estimate at the end of phase gate 3.

An integrated, resource loaded, schedule (including engineering, procurement and construction work scopes) has been completed and approved. This schedule includes detailed activities, activity interdependencies (predecessors and successors), the depicted critical path and activity durations calculated using resource allocation and coordinated with the cost estimate. This schedule should include lessons learned from previous projects.</td><td>Most of the project schedule has been documented and is under review, but not fully approved.

Most of the integrated resource-loaded schedule has been completed. There may be a few minor activities that need further definition such as project resource loading. The schedule includes detailed activities, activity interdependencies (predecessors and successors), the depicted critical path and activity durations calculated using resource allocation.</td><td>Some of the project schedule has been developed and documented with holds for deficiencies.

Some of the master plan schedule has been prepared. There are several activities that need further definition. The schedule includes milestones, major activities, activity interdependencies (predecessors and successors), the depicted critical path, activity durations calculated using valid completed projects, long lead items deliveries discuss with key suppliers, or lessons learned assessments and identification of major constraints.</td><td>Some items that are included in the project schedule have been identified.

Initial thoughts have been applied to the scheduling effort with desired milestone dates in place; however, little thought has been applied to how this impacts the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.</td><td rowspan="2">Not yet started.</td></tr>
<tr><td>** Additional items to consider for Renovation & Revamp projects **
☐ The schedule should involve obtaining early input from the Shutdown/Turnaround Manager

R&R projects require a high level of planning to minimize risk because they interface with existing operations and are many times performed in conjunction with other on-going projects. Shutdowns/turnarounds/outages are special cases in that they are particularly constrained in terms of time and space, requiring very detailed plans and schedules.</td><td>A detailed project schedule has been documented and approved, and includes early input from the shutdown/turnaround manager and interfaces with existing operations and other turnaround projects.</td><td>Most of the R&R items related to the project schedule have been identified, documented and are under review, including the interfaces with existing operations and other turnaround projects. A detailed project schedule is almost completed.</td><td>Some of the R&R items related to the project schedule have been identified and are being assessed, including early input from the shutdown/turnaround manager.</td><td>Little or no meeting time or development hours have been expended on R&R items related to the project schedule.</td></tr>
</table>

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
E. VALUE ENGINEERING	**0**	**1**	**2**	**3**	**4**	**5**
E1. Process Simplification A structured value analysis approach should be in place to identify and document activities or strategies (through studies, reviews) for reducing the number of steps or the amount of equipment needed in the process in order to optimize performance without compromising security. Items to evaluate include: ☐ Redundancies ☐ Over capacity ☐ Discretionary spares ☐ Excessive controls ☐ Other *Comments on Issues:* *The deliverable of this element is a process simplification plan that informs detailed design and is aligned with project requirements. Many times, process simplification is carried out through a series of workshops. Development of this plan may be the result of some of these workshops. Some process simplification effort may have been completed during front end planning, but most will be finalized during detailed design. The result of the Value Engineering process simplification effort typically result in measurable improved outcomes (e.g. reduced process cycle time and improved economics of systems). In some cases, the licensor of the technology needs to be involved in this discussion. For R&R projects, the process simplification should compare "as-is" systems to the desired final configuration.*	**Not required for project.**	**A process simplification plan has been documented and approved by key stakeholders (e.g., project management, operations and maintenance, engineering).** The plan developed includes discussion of overdesign allowances for all equipment and pipe sizing, identification of established industry standards or practices, required redundancies and guidelines on spares and excessive control systems. Guidelines for addressing the overdesign of systems have been identified and confirmed with stakeholders. When possible, benchmarking of similar systems can be used as an evaluation tool. A budget has been established for this effort.	**Most of the process simplification plan has been developed and is under review, but not fully approved.** The plan has minor issues that require resolution such as overdesign allowances or items dealing with equipment spares. Overall, the plan will result in simplification of process allowing for greater productivity.	**Some of the process simplification plan has been developed with open items.** The process simplification plan has several issues that require resolution. The plan does not clearly identify how process simplification will result in improved outcome.	**Some items that are included in the process simplification effort have been identified.** Initial thoughts have been applied to the process simplification effort; however, it has not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
E. VALUE ENGINEERING	**0**	**1**	**2**	**3**	**4**	**5**
E2. Design and Material Alternatives Considered/Rejected A structured approach is in place to consider design and material alternatives including sustainability considerations. Specific activities have been identified to ensure that this process will take place. Items that impact the economic viability of the project should be considered. Items to evaluate include issues such as: ☐ Discretionary scope issues ☐ Expensive materials of construction ☐ Life-cycle analysis of construction methods ☐ Other *Comments on Issues:* *The deliverable of this element is a design and material alternatives plan that informs detailed design. Many times, the development of this plan is carried out through a series of workshops. The plan should consider the availability and relative cost of alternative materials focusing on improving project outcomes.*	**Not required for project.**	**A design and material alternatives plan has been developed, documented and approved by key stakeholders (e.g., engineering, operations and maintenance, business unit, key suppliers).** The plan developed considers the use of construction knowledge, experience in planning, design, procurement, and field activities in the acceptance or rejection of design and material alternatives. Discretionary scope issues, expensive materials for construction, and the life-cycle analysis for construction methods have all been evaluated and approved or rejected with documented reasons for their approval or rejection. Changes as a result of this value engineering effort to date have been incorporated into the design basis and preliminary specifications. A budget has been established for this effort.	**Most of the design and material alternatives plan has been developed and is under review, but not fully approved.** The plan has minor issues that require resolution such as discretionary scope issues, the evaluation of expensive construction materials or coatings to protect cheaper metals.	**Some of the design and material alternatives plan has been developed with open items.** Some of the design and material alternatives plan is documented; however, there are several issues that need to be addressed. Clear evaluation criteria of the plan have not been determined.	**Some items that are included in the design and material alternatives plan have been identified.** Initial thoughts have been applied identifying items in the design and material alternatives plan; however, these have not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
E. VALUE ENGINEERING	**0**	**1**	**2**	**3**	**4**	**5**
E3. Design for Constructability Analysis A structured process is in place for constructability analysis. CII defines constructability as, “the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives. Maximum benefits occur when people with construction knowledge and experience become involved at the very beginning of a project.” Provisions have been made to provide this on an ongoing basis. This process includes examining design options that minimize construction costs while maintaining standards of safety, security, quality, and schedule. This process should be initiated in the front end planning process during concept or detailed scope definition. Elements of constructability during front end planning include: ☐ Constructability program in existence ☐ Construction knowledge/experience used in project planning ☐ Early construction involvement in contracting strategy development ☐ Developing a construction-sensitive project schedule (with operations input and considering operational needs) ☐ Considering major construction methods in basic design approaches ☐ Developing site layouts for efficient construction ☐ Early identification of project team participants for constructability analysis ☐ Usage of advanced information technologies ☐ Other *Comments on Issues:* *The deliverable of this element is a constructability plan that informs detailed design and construction. Many times, the development of this plan is carried out through a series of workshops. Alignment of procurement and engineering work packages should support the construction work packages including the sequence of installation and construction. The extent of modularization or pre-assembly should be finalized early in FEP phase 3 to inform the estimate.*	**Not required for project.**	**A plan for constructability analysis has been developed, documented and approved by key stakeholders (e.g., construction, engineering, operations and maintenance, business unit, contracting, project management) as a basis for detailed design.** The constructability plan is compatible with the project execution plan and is well understood by the key stakeholders and project execution team. The plan incorporates 3D modeling if possible, and takes into consideration tie-ins, existing constraints, lessons learned, the elimination of excessive scope, involvement in contracting strategy, scheduling, etc. Changes resulting from the constructability effort to date have been incorporated into the design basis and preliminary specifications. A budget and schedule have been established for the constructability plan.	**Most of the plan for constructability analysis has been developed and documented as a basis for detailed design and is under review, but is not fully approved.** The plan has minor issues that require resolution, such as the identification of constructability personnel, site layout, use of advanced information technology, some sequences of site activities, etc. A preliminary budget and schedule has been established for this activity.	**Some of the plan for constructability analysis has been developed with open items.** The plan has several issues that require resolution. These issues may include identification of modularization and pre-assembly opportunities, some interfaces with the project team involved, and embedding construction knowledge and experience in the project planning process.	**Some items to be included in the plan for constructability analysis have been identified.** Initial thoughts have been applied to identifying items in the constructability plan; however, these have not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION I – BASIS OF PROJECT DECISION	Definition Level					
	N/A	BEST		MEDIUM		WORST
F. VALUE ENGINEERING	**0**	**1**	**2**	**3**	**4**	**5**
E3. Design for Constructability Analysis (Continued) ** Additional items to consider for Renovation & Revamp projects ** - Install-ability (e.g., smaller components/modules/pre-assembly to facilitate installation in congested areas) - Opportunities to perform as much work as possible outside of shutdowns or outages Developing an operations-sensitive project schedule (e.g., minimization of Shutdown/Turnaround work and hot work in operating areas)	**Not required for project.**	The plan for R&R constructability analysis has been documented, approved, and incorporates installability, performing as much work outside of shutdowns or outages as possible, coordination with concurrent R&R work, tie-in schedule, and the development of an operations sensitive schedule.	Most of the R&R items related to the plan for constructability analysis have been identified, documented and are under review, including installability, performing as much work outside of shutdowns or outages as possible, and the development of an operations sensitive schedule.	Some of the R&R items related to the plan for constructability analysis have been identified and are being assessed.	Little or no meeting time or development hours have been expended on R&R items related to the design for constructability analysis plan.	**Not yet started.**

SECTION II: BASIS OF DESIGN

This section addresses processes and technical information elements that should be evaluated for a full understanding of the engineering/design requirements necessary for the project.

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
F. SITE INFORMATION	**0**	**1**	**2**	**3**	**4**	**5**
F1. Site Location The geographical location(s) of the proposed project has been defined and documented. This involves an assessment of the relative strengths and weaknesses of alternate site locations. A site that meets owner requirements and maximizes benefits for the owner company should be selected. Evaluation of sites may address issues relative to different types of sites (i.e., global country, local, “inside the fence,” or “inside the building”). This decision should consider the long-term needs of the owner company. The selection criteria should include items such as: ☐ General geographic location ☐ Access to the targeted market area ☐ Near sources of raw materials ☐ Local availability and cost of skilled labor (e.g., construction, operation) ☐ Available utilities ☐ Existing facilities ☐ Land availability and costs ☐ Environmental/Sustainability impact ☐ Access (e.g., road, rail, marine, air) ☐ Construction access and feasibility ☐ Security constraints (consider potential security breach points, e.g., storm water system, watercourses) ☐ Political constraints ☐ Legal constraints ☐ Regulatory constraints ☐ Financing requirements ☐ Social issues ☐ Weather ☐ Climate ☐ Other *Comments on Issues:* *The site selection process should be driven by the benefits that the site will bring to the project (e.g., located where the minimum cost of production and distribution can be obtained, room for future expansion, safe living conditions for plant operation, impacts to the surrounding community, and project profitability).*	**Not required for project.**	**The final site has been selected. Reasons for the selection have been documented and approved by key stakeholders (e.g., business unit).** The choice of the final site was based on a complete survey of the advantages and disadvantages of the various geographical areas and factors, and ultimately the available real-estate. The site has been purchased or negotiations are in progress. Principal factors that led to the selection of the final site are documented and agreed upon.	**The final selection has been narrowed to one location. Most of the reasons for this selection have been documented, but the final site selection has not been approved.** The site selection process was narrowed down to one possible location and negotiations may be in progress. There are additional factors that have to be reconciled to meet business requirements, but the site selection is complete and should not change.	**For the considered sites and locations, selection criteria have been developed pending a sensitivity analysis.** The site selection process has considered multiple locations; however, a number of risk factors have not been addressed, including specific owner requirements that maximize the benefits to the owner organization.	**Several sites or locations may have been identified.** Some initial thoughts have been applied to the site selection effort; however, these efforts have not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
F. SITE INFORMATION	**0**	**1**	**2**	**3**	**4**	**5**
F1. Site Location (continued) ** Additional items to consider for Renovation & Revamp projects ** □ Change in intended use of the facility □ Zoning, permitting or other regulatory changes brought about by R&R	**Not required for project.**	The site location has been documented, approved and incorporates changes in the intended use of the facility, zoning, permitting and other regulatory requirements	Most of the R&R items related to the site location have been documented and are under review.	Some of the R&R items related to the site location have been identified and are being assessed, including changes in the intended use of the facility, zoning, permitting and other regulatory requirements.	Little or no meeting time or development hours have been expended on R&R items related to the site location	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
F. SITE INFORMATION	**0**	**1**	**2**	**3**	**4**	**5**
F2. Surveys & Soil Tests Survey and soil test evaluations of the proposed site should be developed and include items such as: □ Topography map □ Overall plant plot plan □ General site description (e.g., terrain, existing structures, spoil removal, areas of hazardous waste) □ Definition of final site elevation □ Benchmark (coordinate and elevation) control system identified □ Spoil area (i.e., location of on-site area or off-site instructions) □ Seismic requirements □ Water table □ Soil percolation rate & conductivity □ Existing contamination □ Ground water flow rates and directions □ Downstream uses of ground water □ Need for soil treatment or replacement □ Description of foundation types □ Allowable bearing capacities □ Pier/pile capacities □ Other	**Not required for project.**	**Survey and soil test information has been documented and approved by key stakeholders (e.g., designers, construction, and project management) as a basis for detailed design.** Reports containing surveys and soil test information have been developed supporting project scope of work definition and design criteria.	**Most survey and soil test information have been documented and draft documents are under review, but not yet approved.** A draft geotechnical report provides initial recommendations for import fill classification, foundation bearing capacity, pier capacity and roadway capacity. A mostly complete topographical and site plan has been developed and includes: overall plot plan, site feature identification, elevations, contours, and benchmarks. Not all documents have been reviewed by key stakeholders and approved.	**Some, but not all, of the surveys and soil tests have been performed.** Geotechnical information is missing from any of the following: soil borings, water table, soil percolation, soil classification, recommendations for import fill classification, foundation bearing capacity, pier capacity and roadway capacity. Topographical and site plan information is missing any of the following: overall plot plan, site features, identification, preliminary elevations, contours, and benchmarks. .	**Survey and soil test information requirements have been identified and some initial thoughts have been applied to this effort.** Little or no meeting time or design/ consulting hours have been expended on this topic and nothing has been documented.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
F. SITE INFORMATION	**0**	**1**	**2**	**3**	**4**	**5**
F3. Environmental Assessment An environmental assessment should be performed for the site to evaluate issues that can impact the cost estimate or delay the project. These issues may include characteristics such as: ☐ Location in an air quality non-compliance zone (such as identified by the U.S. Environmental Protection Agency (EPA) or others) ☐ Location in a wet lands area ☐ Environmental permits now in force ☐ Location of nearest residential area ☐ Ground water monitoring in place ☐ Containment requirements ☐ Existing environmental problems with the site such as: ☐ Asbestos/PCB ☐ Radioactive materials ☐ Contaminated soils ☐ Lead or other heavy metal (e.g. Chromium, Mercury) ☐ Hazardous or toxic chemical/biological contamination ☐ Past/present use of site Sustainability ☐ Archeological ☐ Endangered species ☐ Erosion/sediment control ☐ Other *Comments on Issues:* *Other items typically include: noise level restrictions and standards to comply with. Additionally, environmental permits do not necessarily have to be in hand to achieve a definition level of 1. Moreover, a community outreach plan is typically submitted as part of the completeness of this element. This element typically also considers waste types such as air, fine particles, construction waste, etc.*	**Not required for project.**	**The environmental assessment report has been issued and approved by key stakeholders (e.g., design, HSE, and project management) as a basis for detailed design.** A comprehensive environmental assessment report has been created and includes the following analysis in detail: archeological, endangered species, appropriate environmental oversight regulatory reports, air quality assessment, wetland, and ground water assessment.	**Most of the environmental assessment is complete with major findings documented, and under review, but not yet approved. Stakeholders have reviewed and commented on the draft documents.** A few issues have not been documented such as: extent of environmental problems, archaeological or sediment control. These will need to be addressed in the detailed design phase.	**The environmental assessment has been started but not all findings have been reported.** The following items have been started, but only an initial draft report is available such as: appropriate environmental oversight regulatory reports, wetland, archeological, endangered species, air quality assessment, ground water assessment.	**The environmental assessment requirements have been identified and some initial thoughts have been applied to this effort.** Little or no meeting time or design/ consulting hours have been expended on this topic and nothing has been documented. Environmental documents have not started or there has been little progress.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
F. SITE INFORMATION	**0**	**1**	**2**	**3**	**4**	**5**
F4. Permit Requirements A permitting plan for the project should be in place. The local, state or province, and federal government permits necessary to construct and operate the unit/facility should be identified. These should include items such as: ☐ Construction ☐ Local ☐ Environmental ☐ Transportation ☐ Coastal Development ☐ Security ☐ Fire ☐ Building ☐ Occupancy ☐ Railroad ☐ Levee Board ☐ Highway ☐ Other *Comments on Issues:* *The permitting plan considers and contains objective and impact of permitting on project or facility, and that impact is part of the estimate, schedule, and scope. Additionally, environmental permits are typically submitted during concept or detailed scope phase so that agency approval is received during phase-gate 3 so that costs can be included. Moreover, permits do not necessarily have to be in hand to receive a definition level of 1. Furthermore, Construction knowledge and input are typically taken into account when considering the completeness of this element. Moreover, a community outreach plan is typically submitted as well.*	**Not required for project.**	**A comprehensive permitting plan has been created and approved by key stakeholders (e.g., design, HSE, and project management).** The permitting plan contains detailed descriptions and plans for the following permits: National, regional, local agencies requirements (e.g., transportation, environmental, levee board, coastal, railroad, building, occupancy).	**A draft permitting plan has been documented and is under review, but not yet approved. Stakeholders have reviewed and commented on the draft document.** The permitting plan contains descriptions and plans for the following permits: National, regional, local agencies requirements (e.g., transportation, environmental, levee board, coastal, railroad, building, occupancy). Not all details are complete. Portions of the draft permitting plan have not been approved by key stakeholders.	**A permitting plan has been started but not fully researched.** The permitting investigation has started, but several permits have not been researched. For instance: National, regional, local agencies requirements (e.g., transportation, environmental, levee board, coastal, railroad, building, occupancy).	**The required permits have been identified and some initial thoughts have been applied to this effort.** A full permitting investigation has not been started. Little no meeting time or design/consulting hours have been expended on this topic and nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Original intent of codes and regulations and any “grandfathered” requirements		The original intent of codes and regulations and any “grandfathered” requirements have been fully addressed, documented, and approved.	The original intent of codes and regulations and any “grandfathered” requirements have been documented, but have not been approved by key stakeholders.	The original intent of codes and regulations and any “grandfathered” requirements have been researched but not documented.	Little or no meeting time have been expended on the original intent of codes and regulations and any “grandfathered” requirements.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. SITE INFORMATION	**0**	**1**	**2**	**3**	**4**	**5**
F5. Utility Sources with Supply Conditions A list has been made identifying availability/non-availability or redundancy of site utilities needed to operate the unit/facility. This list includes supply conditions such as temperature, pressure, and quality. Items to consider include: ☐ Potable water ☐ Drinking water ☐ Cooling water ☐ Fire water ☐ Sewers ☐ Power (voltage levels) ☐ Instrument air ☐ Plant air ☐ Gases ☐ Steam ☐ Condensate ☐ Other *Comments on Issues:* *Other items typically include: definition of utilities sources supplied by their party companies through specific contracts, buying or selling utilities at the unit/facility). Construction knowledge and input are typically taken into account when considering the completeness of this element.*	**Not required for project.**	**Utility sources have been identified and fully detailed with relevant process conditions. All redundancy and availability studies relating to the required class of facilities have been completed and approved by key stakeholders as a basis for detailed design.** All utility sources and consumers have been identified and associated process information compiled and included in the list.	**Most utility sources have been sized and temperature, pressure, and flow rate design conditions are identified.** Redundancy and availability studies have been completed to assess sparing/oversizing requirements based on required class of facility. Results have been issued for review, but not approved.	**A list of utilities has been developed and utility sources and requirements have been initially assessed.** Preliminary assessment of utility sources, based on consumer requirements, has been completed and deficiencies noted.	**A preliminary list of required utilities has been started.** Little or no meeting time or design/consulting hours have been expended on this topic and nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Tie-ins to existing facility utility sources		Full evaluation of existing utilities and sources at brownfield site has been completed. Tie-ins to existing utility sources have been identified and vetted through brownfield site representatives.	Assessment has been completed of existing facilities of brownfield site, and options for possible tie-ins have been developed. Results have been issued for review, but not yet approved.	Initial assessment of existing utilities of brownfield site has been started for all applicable utilities.	Initial assessment of existing utilities of brownfield site has been started for only some utilities.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
F. SITE INFORMATION	**0**	**1**	**2**	**3**	**4**	**5**
F6. Fire Protection & Safety Considerations A list of fire and safety related items to be taken into account in the design of the facility should include fire protection practices at the site, available firewater supply (amounts and conditions), special safety and security requirements unique to the site. Evaluation criteria should include: □ Eye wash stations □ Safety showers □ Fire monitors & hydrants □ Foam □ Evacuation plan □ Perimeter Security □ Deluge requirements □ Wind direction indicator devices (i.e., wind socks) □ Alarm systems □ Medical facilities □ Other *Comments on Issues:* *Other items typically include: closed circuit television monitoring systems, process hazard analysis (PHA) study considerations*	**Not required for project.**	**Fire protection and safety requirements have been documented and approved by key stakeholders (e.g., process design, health and safety executives, and project management) as a basis for detailed design.** The fire protection design basis includes: System hydraulic studies, fire water demand, fire and gas detector layout and hardware, hydraulic reports, and safety and security plans have been documented.	**Most of the fire protection and safety requirements have been defined and are under review. The system configuration is being finalized. Stakeholders have reviewed and commented on the draft documents.** A draft fire protection plan, site safety, and security plan have been completed and reviewed with key stakeholders. A few issues such as location of monitors/ hydrants/safety showers or gas detectors have not been finalized.	**Fire protection and safety requirements have been defined, but the system configuration is still being developed.** A draft fire protection plan, site safety, and security plan are being developed. Preliminary definition on the following items has started: location of monitors/hydrants/ safety showers/fire and gas detectors, site safety and security plan.	**Fire protection and safety requirements have been identified and some initial thoughts have been applied to this effort.** Little or no meeting time or design/consulting hours have been expended on this topic and nothing has been documented. General concepts for fire water supply, fire and gas detection, and methods for fire suppression in different areas, have been identified. Concepts for plant evacuation and emergency response have been discussed.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G1. Process Flow Sheets Drawings that provide the process description of the unit/facility should be developed. Evaluation criteria should include: □ Major equipment items □ Flow of materials to and from the major equipment items □ Primary control loops for the major equipment items □ Sufficient information to allow sizing of all process lines □ Other *Comments on Issues:* *Other items typically include: main construction materials for equipment and piping systems*	**Not required for project.**	**Process flow diagrams (PFD's) have been documented and approved by key stakeholders as a basis for detailed design.** Process steps have been optimized for the following: material and energy usage, process and utility lines (e.g., feed, product, intermediate, recycles, purges, relief systems, waste, and major start-up lines). All process, utility lines, primary control loops and packaged systems equipment are shown and sized. Sufficient data is shown to allow sizing of all process and utility lines which includes flow rate, temperature & pressure, phase, and physical properties. Process requirements are noted (e.g., critical elevations, locations, distances, and special valving).	**Most of the PFD's have been issued for review and process hazard analysis (PHA) has been documented and are under review, but not yet approved.** PFD's have been through a multi-discipline review and are essentially complete except for specific defined holds and/or minor deficiencies. Process steps have been optimized for the following: material and energy usage, process and utility lines (e.g., feed, product, intermediate). All process, utility lines, primary control loops and packaged systems equipment are shown and sized. Sufficient data is shown to allow sizing of all process and utility lines which includes flow rate, temperature and pressure, phase, and physical properties. Process requirements are noted (e.g., critical elevations and locations).	**Some PFD's have been issued for review with deficiencies.** Some of the mechanical equipment packages, process equipment, systems equipment, and major off-site and utility equipment are documented with preliminary requirements noted for other equipment. Process, off-site and utility lines are documented with deficiencies. Data is compiled (including flow rate, temperature and pressure, phase, physical properties) to allow sizing of some of the lines. Some preliminary temperature and pressure profiles are documented. Some process requirements are identified (e.g., critical elevations, locations, distances and special valving).	**Preliminary PFD's have been identified and some initial thoughts have been applied to this effort.** Major process equipment is identified and sized along with major process, offsite and utility lines. Preliminary mass flow rates are developed with enough data for preliminary line sizing. Minor process and utility equipment or systems are not fully defined or sized. Boundaries for major packaged systems documented, but the systems not fully defined.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** □ Definition of Owner's requirements for updating existing process flow sheets.		The requirements for updating existing process flow sheets have been fully documented and approved.	The requirements for updating existing process flow sheets have been documented.	The requirements for updating existing process flow sheets are in progress and not documented.	Little or no meeting time have been expended on the requirements for updating existing process flow sheets.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G2. Heat & Material Balances Heat balances are tables of heat input and output for major equipment items (including all heat exchangers) within the unit. Material balances are tables of material input and output for all equipment items within the unit. The documentation of these balances should include: □ Special heat balance tables for reaction systems □ Information on the conditions (e.g., temperature, pressure, , and steady or unsteady state) □ Volumetric amount (e.g., gallons per minute (GPM), liters per second (LPS), cubic feet per minute (CFM)) or mass flow rates □ All relief and environmental systems □ Other	**Not required for project.**	**Heat and material balance process design/ calculations are documented and approved by key stakeholders as a basis for detailed design.** Integrated system temp balances have been completed based on accurate equilibrium/yield data derived from bench scale/pilot plant runs. Calculations have been completed to incorporate any process hazard analysis (PHA) and process flow diagrams (PFD) review recommendations. Process steps have been optimized for material and energy usage. All applicable value adding practices (VAP's) have been applied. Temperature and pressure profiles have been calculated for normal operating conditions as well as upset and start-up conditions. Equipment sizing complete for all equipment, including process, utility, emergency systems and environmental systems.	**Most of the process design/calculations are documented and are under review, but not yet approved.** Integrated system material balances are completed based on accurate equilibrium/yield data. Process steps have been optimized for material and energy usage. All applicable VAP's are being applied. Most of the temperature and pressure profiles are calculated for normal operating conditions as well as upset and start-up conditions. Equipment sizing complete for all equipment, including process, utility, emergency systems and environmental systems. . There are no significant holds for deficiencies.	**Process design calculations are in progress.** Relief and environmental calculations have not been started. Process steps are not optimized for materials and energy. VAP's such as design to capacity, process simplification, value engineering, materials selection, and constructability have not been applied. Accurate equilibrium/yield data is being developed and component material balances have been started. Major process equipment is sized. Preliminary temperature and pressure profiles are calculated. There may be some holds or deficiencies.	**Preliminary mass balances for process blocks or process units with major feed and product streams identified with overall capacities noted.** Component balances have not been calculated. Temperatures and pressures have not been determined. Little or no meeting time or design/ consulting hours have been expended on this topic and little has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** □ Definition of Owner's requirements for updating existing heat and material balances.		The requirements for updating existing process flow sheets fully documented and approved.	The requirements for updating existing heat and material balances have been documented.	The requirements for updating existing heat and material balances have been identified but not documented.	Little or no meeting time has been expended on the requirements for updating existing heat and material balances.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G3. Piping & Instrumentation Diagrams (P&IDs) These are often referred to by different companies as: EFDs – Engineering Flow Diagrams MFDs – Mechanical Flow Diagrams PMCDs – Process & Mechanical Control Diagrams In general, P&IDs are considered to be a critical element within the scope definition package of an industrial project. P&IDs should address the following areas: ☐ Equipment ☐ Piping ☐ Valves ☐ Piping specialty items ☐ Utilities ☐ Instrumentation ☐ Safety systems ☐ Special notations ☐ Other *Comments on Issues:* *Some owners may want to perform the official process hazard analysis (PHA) later in detailed engineering. If that is the case, they need to be aware that significant scope increase may result after the PHA is complete. That is a risk. If a PHA is not conducted in FEED, then this element should not be assessed as a definition level 1 or 2.* *Since incomplete information on P&ID's is frequently identified as a source of project escalation, it is important to understand their level of completeness. It is unlikely that P&ID's to be completely defined in a project's scope definition package. However, the P&ID's must be complete enough to support the accuracy of the estimate required. Moreover, instrumentation sizing and selection are typically completed.*	**Not required for project.**	**P&IDs are complete and approved by key stakeholders as a basis for detailed design.** P&ID's are updated per PHA review. All applicable value adding practices (VAP's) are completed. All equipment, including packaged systems and their component equipment and controls, are documented (along with complete equipment data, nozzle sizes, and HP/energy consumption). All lines documented (including process, recycles, purges, off-sites, utility, relief systems, waste, start-up lines, packaged systems). All lines sized, numbered, and piping material specifications noted. All special line requirements noted (e.g., slope, do-not-pocket). All equipment and piping insulation/tracing shown and specified. All instrumentation (control loops, primary elements with sizes/meter runs, motor controls, interlocks) tagged and shown with sufficient detail to allow design disciplines to proceed with detail design. All relief devices and relief systems shown with sizes and relief conditions noted. All manual valves shown and special requirements noted. Critical process requirements are clearly identified on the P&IDs (slope, no pocket, steam out). All piping specialties documented and sized.	**Most P&IDs are complete and issued for PHA, but are not yet approved.** P&IDs have been through a multi-discipline review and are essentially complete except for defined holds and/or minor deficiencies. VAP's are being applied. All equipment, including package systems and component equipment and controls, are identified (tagged). Equipment data is listed for all equipment with only minor deficiencies. All process and utility lines are identified along with size, number, piping material specifications, and insulation and tracing requirements. All instrumentation (e.g., control loops, primary elements with sizes/meter runs, motor controls, interlocks) is identified (tagged). All relief devices and relief systems identified with sizes and relief conditions noted. All manual valves identified and special requirements noted (e.g., car sealed closed (CSC), and car sealed open (CSO)). Critical process requirements are clearly identified (e.g., slope, no pocket, steam out). All piping specialties documented and sized.	**P&ID's are issued for review, with significant holds and deficiencies.** All process equipment is identified, as is most of the other mechanical equipment, all with consistent tag numbers. Packaged systems and their boundaries are shown with major components along with key or specified controls. Equipment data is listed for most of the process equipment and other equipment as available. Types of motor drivers are shown for all equipment including horse power (HP)/energy where known. Most process and utility lines are shown along with size, number, piping material specifications, insulation, and tracing requirements as available. All instrumentation (e.g., control loops, primary elements, motor controls, interlocks) is identified (tagged) with sizes provided where known. Most manual valves are identified. Piping specialties are identified (tagged), with sizes if known.	**Preliminary P&IDs are developed and include major process and off-site equipment, utility lines, and critical instrument control loops with only partial definition.** Major piping material specifications have been identified. Packaged systems' boundaries are identified. Little or no meeting time or design/ consulting hours have been expended on this topic and little has been documented.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
H. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G3. Piping & Instrumentation Diagrams (P&IDs) continued ** Additional items to consider for Renovation & Revamp projects ** □ Tie-in points □ Accuracy of existing P&ID's (field verify) □ Scope of Work on existing P&IDs (clouding or shading to indicate: new, refurbished, modified, and/or relocated equipment, piping, instruments, and controls).	**Not required for project.**	Items related to tie-in points, accuracy of existing P&ID's and scope of work on existing P&ID's has been fully addressed, documented and approved.	Most items related to tie-in points, the accuracy of existing P&ID's, and the scope of work on the existing P&ID's has been addressed and documented.	Some items related to tie-in points, the accuracy of existing P&ID's and the scope of work on the existing P&ID's has been addressed, but little has been documented.	Little or no meeting time or design hours have been expended on items related to tie-in points, the accuracy of existing P&ID's and the scope of work on the existing P&ID's.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G4. Process Safety Management (PSM) This element refers to a formal Process Safety Management Hazards Analysis to identify potential risk of injury to the environment or populace. Each national government (or organization) will have their specific PSM compliance requirements (for example, in the U.S., OSHA Regulation 1910.119 compliance is required). The important issue is whether the owner has clearly communicated the requirements, methodology, and responsibility for the various activities. If the PSM has not been conducted, the team should consider the potential of risk that could affect the schedule and cost of the project.	**Not required for project.**	**Process safety management (PSM) compliance requirements and methodology are documented and approved by key stakeholders as a basis for detailed design. Process hazard analysis (PHA) and safety integrity levels (SIL's) are completed and approved.** All activities required for PSM compliance have been identified and responsibilities assigned. Deliverables required for PSM compliance from suppliers and contractors have been documented and communicated to the responsible parties.	**Most process safety management (PSM) compliance requirements and methodology have been developed, but not yet approved.** Activities required for PSM compliance identified. Preliminary PHA's have been prepared using process flow diagrams (PFD's).	**Some process safety management (PSM) compliance requirements and methodology have been developed.** Some items related to PSM have been addressed, but little has been documented.	**Preliminary process safety management (PSM) options have been considered and some initial thoughts have been applied to this effort.** Little or no meeting time or design/consulting hours have been expended on this topic and nothing has been documented.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G5. Utility Flow Diagrams (UFD's) Utility flow diagrams are similar to process and instrumentation diagrams (P&IDs) in that they show all utility lines from generation or supply (i.e., pipeline). They are generally laid out in a manner to represent the geographical layout of the plant. Utility flow diagrams are evaluated using the same issue process as P&IDs. *Comments on Issues:* *In many cases, the UFD's are documented on the P&ID's and are not stand alone deliverables. UFD's are closer to a PFD level of detail, including piping, isolation valves, instrumentation, and equipment. Additionally, the sources of all utilities are identified and their origin is known inside and outside the plant.*	**Not required for project.**	**UFD's are complete and approved by key stakeholders as a basis for detail design.** UFD's have been through proper process hazard analysis (PHA) and comments/ refinements have been incorporated. All relevant utilities are included, as well as a clear illustration of the sources of the utilities and the consumers of the utilities (with equipment or system numbers, as applicable). An energy/ material balance has been completed and shown on the UFD's, fully analyzing consumption requirements and sizing utility sources properly (i.e., boiler size based on steam demand requirements). Preliminary hydraulic analysis has been completed to validate piping and relief system sizing. Basic process data has been developed for each utility and is included on the UFD, along with each utility source supply/consumption rate.	**Most UFD's are complete and issued for final review and PHA.** UFD's have been through a review process and are essentially complete except for specific defined holds and/or minor deficiencies. Most relevant utilities are included, as well as a clear illustration of the sources of the utilities and the consumers of the utilities. An energy/material balance has been mostly completed, but not fully documented. UFD's are closer to a PFD level of detail, including piping, isolation valves, instrumentation, and equipment. Basic process data has been developed for each utility and is included on the UFD.	**UFD's are issued for review, with significant holds and deficiencies.** Preliminary UFD's have been developed for review. Some relevant utilities are included, as well as a clear illustration of the sources of the utilities and the consumers of the utilities.	**UFD's are roughly sketched with main systems and interconnections identified.** UFD sketches have been drafted and they include the relevant utilities, supply sources and consumers. Little or no meeting time or design/ consulting hours have been expended on this topic and little or nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects □ Tie-in points □ Accuracy of existing UFD's (field verify) □ Scope of Work on existing UFD's (clouding or shading to indicate: new, refurbished, modified, and/or relocated equipment, piping, instruments, and controls).		Items related to tie-in points, accuracy of existing UFD's and scope of work have been fully addressed, documented, and approved by key stakeholders.	Items related to tie-in points, accuracy of existing UFD's and scope of work have been essentially completed, pending review.	Items related to tie-in points, accuracy of existing UFD's and scope of work are still in development.	Little or no meeting time or design/ consulting hours have been expended on this topic and nothing has been documented.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G6. Specifications General specifications for the design, performance, manufacturing, and material and code requirements should be documented, reviewed and approved for further work. These specifications should include the items such as: □ Equipment and Piping Specification Philosophy □ Classes of equipment (e.g. pumps, exchangers, vessels) □ Process pipe heating □ Process □ Freeze □ Jacketed □ Process pipe cooling □ Jacketed □ Traced □ Piping Service Index □ Piping design □ Protective Coating □ Insulation □ Valves □ Bolts/Gaskets □ Electrical/Instrumentation □ Civil, Building& Infrastructure □ Fire Protection □ Other	**Not required for project.**	**All specifications are appropriately customized for the project scope and approved by key stakeholders as a basis for detailed design.** General specification philosophy and core process/mechanical specifications have been documented (e.g., civil, coating/insulation/refractory (CIR), electrical, fire protection, equipment, heating and cooling, instrumentation, piping, and painting). Each specification package includes relevant standard requirements, drawings, data sheets, inspection, and testing requirement sheets (ITRS) and documentation requirement sheets (DRS) as well as project specific addenda (PSA) and location specific addenda (LSA). Specification and associated attachments are identifiable with a unique numbering system.	**Most specifications are documented and are under review, but not yet approved.** A few issues are pending clarification or need resolution in the core specification, standard drawings, PSA, and LSA.	**Specifications are being defined and developed. The specification package is missing key data elements.** Important pieces of information related to design/operating conditions, area classification requirements, design requirements, industry standards and site data are missing in the core specifications. Associated drawings do not reflect the intent of the specifications being prepared. PSA, LSA, and associated drawings are partially complete.	**Specifications development work has started and some initial thoughts have been applied to this effort.** Necessary data for development of specification packages is being identified, but actual work of developing specifications has not started. Little or no meeting time or design/ consulting hours have been expended on this topic and little or nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** □ Reconciliation of original specifications with current project specifications.		Reconciliation of original specifications with current project specifications is complete and approved.	Specifications being verified with existing plant documentation. Inconsistency and missing documentation identified and action taken.	Specifications being verified with existing plant documentation.	Specification verification with existing plant documentation started. Little or nothing has been documented.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G7. Piping System Requirements Piping system stress guidelines and requirements should be provided to ensure that piping system design can be estimated and scheduled. The owner must communicate the standards, methodology and record documentation required to support the piping system design effort. Criteria for design of piping systems should include: ☐ Allowable forces and moments on equipment ☐ Graphical representation of piping line sizes that require analysis based on: ☐ Temperature ☐ Pressure ☐ Cyclic conditions ☐ Flex ☐ Stress ☐ Pulsation ☐ Seismic ☐ Other *Comments on Issues:* *Advanced work packaging is typically considered when assessing the completeness of this element.*	**Not required for project.**	**Piping system requirements are complete and approved by key stakeholders (e.g., operations and maintenance, process engineering, project management) as a basis for detailed design.** These requirements include standards, typical support drawings, methodology, selection criteria and other documentation necessary to support piping design. Critical lines of the project that require stress analysis are identified and preliminary analysis performed based on guidelines and documented with necessary technical information such as piping and instrumentation diagram (P&ID) reference, line list, service fluid, operating and design pressure/temperature, allowable forces and moments, service conditions.	**Most piping system requirements are documented and are under review, but not yet approved.** The guideline document including standards, typical support drawings, methodology, selection criteria and other documentation necessary to support piping design is essentially developed with minor additions required. Critical lines of the project that require stress analysis are identified and preliminary analysis performed and documented with minor necessary technical information missing on P&ID reference, line list, service fluid, operating and design pressure/temperature, allowable forces and moments, service conditions, which will be finalized during detailed design stage.	**Some piping system requirements are defined.** The guideline document to support piping system stress analysis and the critical line list is under development with a number of open issues.	**Piping system requirements started.** The guideline document to support piping system stress analysis and the identification of the critical lines has been started. Little or no meeting time or design/ consulting hours have been expended on this topic and little or nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Verification of existing conditions: hangers, supports, anchors, wall thickness, etc. ☐ Field verify existing lines that will be modified and requiring stress analysis back to all anchor points ☐ Ensure lines are functioning, available and active		Existing lines including conditions and stress analysis have been verified, reviewed, and approved.	Existing lines including conditions and stress analysis have been verified, reviewed, but not yet approved.	Some documentation available for existing piping systems, critical lines, and as-built records.	Existing requirements being developed. Little or nothing has been documented.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G8. Plot Plan The plot plan will show the location of new work in relation to adjoining units or facilities. It should include items such as: □ Plant grid system with coordinates □ Unit limits □ Gates, fences and/or barriers □ Lighting requirements □ Off-site facilities □ Tank farms □ Roads & access ways □ Roads □ Rail facilities □ Green space □ Buildings □ Major pipe racks □ Laydown areas □ Construction/fabrication areas □ Other *Comments on Issues:* *Construction knowledge and input are typically taken into account when considering the completeness of this element. Additionally, a siting review is typically included to ensure compliance with client requirements. Moreover, elevation drawings and regulatory requirements are typically incorporated into the plot plan when considering the completeness of this element.*	**Not required for project.**	The plot plan is complete and approved by key stakeholders (i.e., operations) as a basis for detailed design. The layout and spacing was reviewed in the process hazards analysis (PHA) and recommendations were incorporated. The plot plan is consistent with the plant grid system and required surveying is complete. All units, major process equipment, pipe racks, buildings, utilities, off-site facilities, tank farms, roads and rail lines, fire protection systems, construction, laydown areas, gates and fencing are documented and approved. Equipment spacing is per project specifications and dimensions are sourced from vendor supplied information, if available.	Most of the plot plan is complete and issued for PHA. The plot plan is mostly consistent with the plant grid system and most required surveying is complete. Most units, major process equipment, pipe racks, buildings, utilities, off-site facilities, tank farms, roads and rail lines, fire protection systems, construction and laydown areas, gate and fencing are documented. There may be minor holds.	**Some of the plot plan is prepared with holds and deficiencies.** Some units and major process equipment are identified. Some pipe racks, buildings, utilities, off-sites, tank farms, roads and rail lines, fire protection systems, construction and laydown areas, gates and fencing are identified.	**Plot plan development has started with some initial thoughts applied to this effort.** General areas are outlined for process, utilities and off-site facilities. Plant grid system and surveying has not been conducted. A dialog has started with plant operations, utility and safety departments. Little or no meeting time or design/ consulting hours have been expended on this topic and little or nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** □ Establish project specific vertical and horizontal reference points for all participants		All project specific vertical and horizontal reference points for all participants have been verified, documented, and approved.	Most of the project specific vertical and horizontal reference points for all participants have been verified and documented, but not yet approved.	Some of the project specific vertical and horizontal reference points have been documented.	Little or no effort has been done to establish the project specific vertical and horizontal reference points.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G9. Mechanical Equipment List The mechanical equipment list should identify all mechanical equipment by tag number, in summary format, to support the project. The list should define items such as: □ Existing sources: □ Modified □ Relocated □ Dismantled □ Re-rated □ New sources: □ Purchased new □ Purchased used □ Relative sizes □ Weights □ Location □ Capacities □ Materials □ Utility Requirements – Power, voltage, air pressure, etc. □ Flow diagrams □ Process Conditions – Min/Max/Design temperature, pressure, flow rates, etc. □ Insulation & painting requirements □ Equipment related ladders and platforms □ Other (Quality, Inspection, Licensing, General remarks, etc.) *Comments on Issues:* *Major equipment items are typically those identified on PFD's, packaged equipment, have long delivery times, make up a large percentage of the project cost and are critical to project success. Minor equipment items are typically ancillary support equipment to Major items or miscellaneous utility related items. These are typically items of low cost relative to Major items or items that may be covered in an allowance. Source indicates the origin of the equipment: new, used, relocated, modified, as well as physical location of the vendor (on-site contractor, domestic, overseas, etc.). All commercial related information (weights and final dimensions) is assumed to be captured in the procurement strategy. Construction knowledge and input are typically taken into account when considering the completeness of this element.*	**Not required for project.**	**All mechanical equipment has been listed, tag numbers assigned and all pertinent data tabulated. The equipment list has been reviewed and approved by key stakeholders as a basis for detailed design.** All equipment sources have been identified. All items have associated piping and instrumentation diagrams (P&ID's) and process flow diagrams (PFD's) referenced. All items have equipment type and configuration listed. Process conditions are documented for all items. Overall dimensions and weights are identified based on vendor drawings or cut sheets. All utility requirements are quantified. All items have materials of construction identified. The selected or preferred vendor is identified for all items.	**Most equipment has been listed, tag numbers assigned and pertinent data tabulated. The document is under review, but not yet approved.** Most major and minor equipment sources have been identified with the associated P&ID's referenced. Most items have equipment type listed and dimensions and weights identified. Process conditions are documented for most major and most minor items. Utility requirements are quantified. Most items have materials of construction identified. The selected or preferred vendor is identified for major equipment and preferred vendor for minor.	**Some equipment has been listed, with tag numbers and pertinent data tabulated.** Some major and minor equipment sources have been identified. Some items have equipment type listed. Process conditions are documented for most major and some minor items. Approximate overall dimensions and weights identified for most items. Utility requirements quantified for major items. Materials of construction are identified for major items. Some preferred vendors are identified for major equipment and potential vendors for minor.	**Mechanical equipment list development has started with minimal data tabulated.** Little or no meeting time or design/ consulting hours have been expended on this topic and little or nothing has been documented.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
H. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G9. Mechanical Equipment List (continued) ** Additional items to consider for Renovation & Revamp projects ** Existing equipment condition with consideration for maintenance/repair	**Not required for project.**	Applicability and condition of existing equipment has been verified, documented and approved. All original documentation has been located and organized.	Applicability and condition of existing equipment has been mostly documented, but not yet approved. Most original documentation has been located and organized.	Some evaluation of applicability and condition of existing equipment is documented. Some original documentation has been located.	Existing equipment to be evaluated is known. Little or no meeting time or design/ consulting hours have been expended on this topic and little has been documented.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G10. Line List The line list designates all pipe lines in the project (including utilities). It should include items such as: ☐ Unique number for each line: ☐ Size ☐ Service ☐ Termination ☐ Origin ☐ Reference P&ID ☐ Normal and upset operating: ☐ Temperature ☐ Pressure ☐ Design temperature and pressure ☐ Test requirements ☐ Pipe specifications ☐ Insulation requirements ☐ Paint requirements ☐ Special Process Requirements (Steam Out) ☐ Other *Comments on Issues:* *Construction knowledge and input are typically taken into account when considering the completeness of this element. Other items to consider: hydro testing/pressure requirements identified.*	**Not required for project.**	**The line list is complete and approved by key stakeholders as a basis for detailed design.** The line list has been verified per piping and instrumentation diagram (P&ID) reviews and process hazards analysis (PHA). All lines (e.g., process, off-site, utility, start-up, bypass, relief, vent, waste) are listed above the minimum size requirement for the project. Pertinent information is listed for all lines (e.g., line number, service, from/to, size, pressure class, piping material specification, normal/maximum/design temperature and pressure, test requirements, heat tracing and insulation requirements, and painting requirements). Special process line conditions are listed (e.g., slope, no pockets, steam out and emergency conditions).	**Most of the line list is complete and issued for PHA with minor defined holds for deficiencies.** Most of the lines are listed (e.g., process, off-site, utility, start-up, bypass, relief, vent, waste). Pertinent information is listed for most lines (e.g., line number, service, from/to, size, pressure class, piping material specification, normal/maximum/design temperature and pressure, test requirements, heat tracing and insulation requirements, and painting requirements).	**The line list is partially complete with holds for deficiencies.** Some of the process and major off-site and utility lines are listed. Listed lines include as a minimum: line number, service, from/to, size, pressure class, piping material specification and heat tracing/ insulation requirements. Other information should be listed as available.	**Line list development has started, but not documented.** Major process and utility lines are identified. Little or no meeting time or design/ consulting hours have been expended on this topic and little or nothing has been documented.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	**BEST**		**MEDIUM**		**WORST**
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G11. Tie-in List A list of all piping tie-ins to existing lines should be developed. It should include items such as: ☐ Location ☐ Existing Equipment/Line Number ☐ Insulation removal requirements ☐ Decontamination requirements ☐ Reference drawings ☐ Pipe specifications ☐ Timing/schedule ☐ Type of tie-in/size: ☐ Hot tap ☐ Flange/Bolt up ☐ Weld ☐ Cold cut ☐ Screwed ☐ Cut and weld ☐ Other *Comments on Issues:* *Construction knowledge and input are typically taken into account when considering the completeness of this element.*	**Not required for project.**	**Tie-in list is complete and approved by key stakeholders as a basis for detailed design.** All of the tie-in locations have been approved and signed off by operations and construction and finalized per piping and instrumentation diagrams (P&ID's) reviews and process hazards analysis (PHA). The timing of all tie-ins has been identified (e.g., early, opportunities, pre-turn around, turn around or post turn around). Demolition requirements affecting tie-ins have been identified.	**Most of the tie-in list is complete with minor holds for deficiencies.** The majority of the tie-in locations have been field verified, approved, and signed off by operations and construction. The timing of most tie-ins has been identified (e.g., early, opportunities, pre-turn around, turn around or post turn around). Demolition requirements affecting tie-ins have mostly been identified.	**Preliminary tie-in list is complete with significant deficiencies.** Some tie-ins have been identified on the P&ID's. The preliminary approval of tie-in sequence has been given from process, design, and operations.	**Preliminary tie-in list started.** Critical process tie-ins have been identified on the P&ID's. Little or no meeting time or design/ consulting hours have been expended on this topic and little has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Field verify condition of isolation points ☐ Sequencing of tie-ins with production planning requirements to ensure safety and on-going operations ☐ Establish decontamination and purge requirements to support tie-ins ☐ Tie in locations approved by Operations ☐ Ensure and conduct a structured process to validate tie-ins and tie-in strategy.		All of the tie-in items related to R&R have been documented and approved.	Most of the tie-in items related to R&R have been documented, but not yet approved.	Some of the tie-in items related to R&R have been discussed.	Little or no meeting time or design hours have been expended on tie-in items related to R&R.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G12. Piping Specialty Items List This list is used to specify in-line piping items not covered by piping material specifications. It should identify all special items by tag number, in summary format. It should include items such as: ☐ Tag numbers ☐ Quantities ☐ Piping plans referenced ☐ Piping details ☐ Full purchase description ☐ Materials of construction ☐ P&IDs referenced ☐ Line/equipment numbers ☐ Other *Comments on Issues:* *Examples of specialty items typically include: headers, distribution systems, station samples systems, T-type strainers, steam traps, injection quill, flame arrestors, hoses, couplings, and gamma jets.*	**Not required for project.**	**Piping specialty items list is complete and approved by key stakeholders as a basis for detailed design.** All piping specialty items have been approved and signed off by operations and finalized per piping and instrumentation diagrams (P&ID's) reviews and process hazards analysis (PHA). All piping specialty items are listed (e.g., process, off-site, utility, start-up, bypass, relief, vent, and waste). Necessary information is available for all items which include: the item number, from/to, size, pressure class, piping material specification, normal/maximum/design temperature & pressure, test requirements, heat tracing & insulation requirements, and painting requirements. Additionally, special construction notes (e.g., slope, no pockets, and emergency conditions) for the lines are listed.	**Most of the piping specialty items list is complete with minor holds/ deficiencies and issued for PHA and approval.** Most of the piping specialty items are listed (e.g., process, off-site, utility, start-up, bypass, relief, vent, waste). The information is available for all items: item number, from/to, size, pressure class, piping material specification, normal/maximum/design temperature & pressure, test requirements, heat tracing & insulation requirements, and painting requirements.	**Some of the piping specialty items list is under development with deficiencies.** Some piping specialty items are identified. Items include the necessary information such as: item number, from/to, size, pressure class, piping material specification and heat tracing/ insulation requirements under development.	**Piping specialty items list started, but not documented.** Key piping specialty items have been identified, but supporting data not developed. Little or no meeting time or design/ consulting hours have been expended on this topic and little has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ The specialty items list to interface with existing site is complete.		The specialty items list to interface with existing site is complete and approved.	The specialty items list to interface with existing site is mostly complete, but not yet approved.	The specialty items list to interface with existing site is under development.	A small number of specialty items known to interface with the existing site have been identified.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
G. PROCESS/MECHANICAL	**0**	**1**	**2**	**3**	**4**	**5**
G13. Instrument Index This is a complete listing of all instruments by tag number. Evaluation criteria should include: ☐ Tag number ☐ Instrument type ☐ Service ☐ P&ID number ☐ Line number ☐ Insulation, paint, heat tracing, winterization, etc. requirements ☐ Relieving devices (e.g., relief valves, rupture disks) ☐ Other *Comments on Issues:* *The instrument index is developed to determine instrument types and quantities.*	**Not required for project.**	**The instrument index is complete and approved by key stakeholders as a basis for detailed design.** The instrument index has been approved and signed off by operations, and finalized per piping and instrumentation diagrams (P&ID's) reviews and process hazards analysis (PHA). Instrument tags, types, P&ID numbers, instrument manufacturers, model numbers, ranges & trip points are included. The index also includes relief, on/off and control valves. Instruments pertaining to package equipment are also included based on equipment specific to the project.	**The instrument index is essentially complete and issued for PHA and approval.** Most instrument tags, types, P&ID numbers, instrument manufacturers, model numbers, ranges and trip points are included. The index also includes relief, on/off and control valves. Instruments pertaining to package equipment are also included based on equipment specific to the project.	**The instrument index is under review, with significant holds and deficiencies.** Some instrument tags, types, P&ID numbers, instrument manufacturers, model numbers, and ranges. The index also includes, on/off and control valves. Trip points and relief valves are not included, awaiting the alarm study. Instruments pertaining to package equipment are not included; or are not based on equipment specific to the project, but based on generic package equipment data.	**The preliminary instrument index is started.** A rough list of instruments including types, make and model numbers are defined with quantities for the purpose of preliminary cost. The preliminary index addresses major process and off-site equipment, and utility lines.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Instrument Status (e.g., new, existing, relocate, modify, refurbish, or dismantle) ☐ Existing instrumentation and valves (e.g., trim, functionality, leakage, closure)		The instrument status and existing instrumentation and valves are completely defined documented, and approved by key stakeholders.	Most of the instrument status, existing instrumentation, and valves are documented, but not yet reviewed and approved	Some of the instrument status, existing instrumentation, and valves have been identified.	Little or no meeting time or design hours have been expended on the instrument status and existing instrumentation and valves.	

SECTION II – BASIS OF DESIGN	**Definition Level**					
	N/A	**BEST**		**MEDIUM**		**WORST**
G. EQUIPMENT SCOPE	**0**	**1**	**2**	**3**	**4**	**5**
H1. Equipment Status Has the equipment been defined, inquired, bid tabbed, or purchased? This includes all engineered equipment such as: ☐ Process ☐ Electrical ☐ Mechanical ☐ Heating, ventilation, air conditioning (HVAC) ☐ Instruments ☐ Security-related equipment ☐ Specialty items ☐ Distributed control systems ☐ Other Evaluation criteria should include: ☐ Equipment data sheets ☐ Number of items inquired ☐ Number of items with approved bid tabs ☐ Number of items purchased ☐ Considerations for pre-fab vs. stick build ☐ Other *Comments on Issues:* *Major equipment items are typically those identified on process flow diagrams (PFD's), packaged equipment, have long delivery times, make up a large percentage of the project cost and are critical to project success. Minor equipment items are typically ancillary support equipment to major items or miscellaneous utility related items. These are typically items of low cost relative to major items or items that may be covered in an allowance. Data sheet development typically precedes specification package development. Often items are preliminary inquired with a data sheet only to satisfy FEED requirements. Furthermore, the schedule is typically considered here to incorporate delivery times of long-lead items and critical equipment.*	**Not required for project.**	**All major and minor equipment items have been approved by key stakeholders and are ready for purchase.** Data sheets and specification packages have been developed and approved for all major and minor equipment items. Multiple bids have been received for all major and minor equipment items from approved suppliers. Bid tabs have been created for all major and minor items. Some major equipment items may have been purchased and the remaining major and some minor items are approved for purchase.	**All major and most minor equipment items have been defined, inquired, bid tabbed, and ready for purchase.** Data sheets and specification packages have been developed and approved for all major and most minor equipment items. Multiple bids have been received for all major and most minor equipment items from approved suppliers. Bid tabs have been created for most major and some minor items. A few major equipment items may have been purchased and some major and a few minor items are approved for purchase.	**Most major and some minor equipment items have been defined, inquired, and bid tabbed.** Data sheets and specification packages have been developed for most major and some minor equipment items. Bids have been received for most major and some minor equipment items. Bid tabs have been created for some major items. Some items have been approved for purchase.	**Some major and a few minor equipment items have been defined and inquired.** Data sheets and specification packages have been developed for some major and a few minor equipment items. Bids have been received for some major and a few minor equipment items. Bid tabs have been created for a few major equipment items. A few equipment items are approved for purchase.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Modifications and refurbishment of existing equipment.	**Not required for project.**	Modification and refurbishment scope of existing equipment is documented and approved by key stakeholders.	Most of the modification and refurbishment scope of existing equipment is documented, but not yet approved.	Some modification and refurbishment scope of existing equipment is developed.	Modification and refurbishment scope of existing equipment has just started.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
H. EQUIPMENT SCOPE	**0**	**1**	**2**	**3**	**4**	**5**
H2. Equipment Location Drawings Equipment location/arrangement drawings identify the specific location of each item of equipment in a project. These drawings should identify items such as: □ Elevation views of equipment and platforms □ Top of steel for platforms and pipe racks □ Paving and foundation elevations □ Coordinates of all equipment □ Other *Comments on Issues:* *Major equipment items are typically those identified on process flow diagrams (PFD's), packaged equipment, have long delivery times, make up a large percentage of the project cost and are critical to project success. Minor equipment items are typically ancillary support equipment to major items or miscellaneous utility related items. These are typically items of low cost relative to major items or items that may be covered in an allowance. Data sheet development typically precedes specification package development. Often items are preliminary inquired with a data sheet only to satisfy FEED requirements. Construction knowledge and input are typically taken into account when considering the completeness of this element.*	**Not required for project.**	**Equipment location drawings are developed using 3-D modelling and approved via preliminary model review by key stakeholders as a basis for detailed design.** Equipment location drawings have been through process hazards analysis (PHA), and comments/refinements have been incorporated. All major and minor equipment items are shown in the equipment location drawings, along with their relevant information, including coordinates of equipment, elevations, and tag numbers. Proper distances between all items are considered from the safety, operations, and maintenance points of view. 3-D modeling was utilized to develop the location drawings.	**Equipment location drawings are mostly complete and issued for review.** Equipment location drawings have been submitted for PHA, and are in the final stages of the review process. All major and some minor equipment items are shown on the equipment location drawings, along with their relevant information including coordinates of equipment, elevations, and tag numbers. Proper distances between most equipment items are considered from the safety, operations, and maintenance points of view.	**Equipment location drawings are developed, with some holds for deficiencies.** Most major equipment items are shown on equipment location drawings, along with their relevant data, including coordinates, tag numbers and elevation. Approximate distances between most major equipment items are considered from the safety, operations and maintenance points of view.	**Equipment location drawings have been developed for only a few major equipment items.** Equipment location drawings include rough diagrammatic representation of a few major equipment items. Boundaries, approximate location and elevation information for a few major equipment items are included in the drawings.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** □ Clearly identify existing equipment to be removed or rearranged, or to remain in place		Existing equipment items to be removed, rearranged, or to remain in place, are documented and approved by key stakeholders.	Most of the existing equipment items to be removed, rearranged, or to remain in place, are documented, but not yet approved.	Some of the existing equipment to be removed, rearranged, or to remain in place are identified on the drawings.	A preliminary evaluation of existing equipment to be removed or rearranged has been started.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
H. EQUIPMENT SCOPE	**0**	**1**	**2**	**3**	**4**	**5**
H3. Equipment Utility Requirements A tabulated list of utility requirements for all equipment items should be developed. The list should identify requirements such as: □ Air □ Plant Air □ Instrument Air □ Vacuum System □ Water □ Plant Water □ Chilled Water □ Hot Water □ Process Water (e.g., carbon filtered, degasified, demineralized) □ Steam □ High Pressure □ Medium Pressure □ Low Pressure □ Condensate System □ Fuel ○ Natural Gas □ Fuel Oil □ Propane □ Alternatives □ Ventilation □ HVAC □ Refrigeration □ Process ○ Carbon dioxide □ Ammonia □ Nitrogen □ Oxygen □ Others □ Process □ Freeze □ Jacketed □ Process pipe cooling □ Jacketed □ Traced □ Other	**Not required for project.**	**Equipment utility requirements are defined and approved by key stakeholders as a basis for detailed design.** A separate table is provided for each utility service and includes details (e.g., equipment tag number, description of equipment, service condition required, flow/quantity, method of supply, service levels, metering/monitoring methodology, emergency shut off provisions, service provider details, and special requirements for heating /cooling, freeze protection/tracing). Process hazards analysis (PHA) recommendations are incorporated into the list.	**Most equipment utility requirements are defined and documented to match up with the supply conditions, but are missing minor details.** The utilities list is mostly complete but may be missing information such as equipment tag numbers, method of supply, emergency shut off provisions or information on secondary utility vendor packages.	**Some equipment utility requirements are defined.** Missing pieces of information could have significant cost and schedule implications. The utilities list is being developed, and data collection activities are in progress. Some major/critical equipment's requirements are not well defined.	**Equipment utility requirements definition and development work has started.** General utility requirement details are known, but not appropriately documented. Individual equipment item utility requirements are not completely defined.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
H. CIVIL, STRUCTURAL & ARCHITECTURAL	**0**	**1**	**2**	**3**	**4**	**5**
I1. Civil/Structural Requirements Civil/structural requirements should be developed and include the issues such as the following: ☐ Structural drawings ☐ Pipe racks/supports ☐ Elevation views ☐ Top of steel for platforms ☐ High point elevations for grade, paving, and foundations ☐ Location of equipment and offices ☐ Construction materials (e.g., concrete, steel, client standards) ☐ Physical requirements ☐ Seismic requirements ☐ Minimum clearances ☐ Fireproofing requirements ☐ Corrosion control requirements/required protective coatings ☐ Enclosure requirements (e.g., open, closed, covered) ☐ Secondary containment ☐ Environmental sustainability considerations ☐ Dikes ☐ Storm sewers ☐ Client specifications (e.g., basis for design loads, vulnerability and risk assessments) ☐ Future expansion considerations ☐ Other *Comments on Issues:* *Other items typically include: trenches for drainage systems and duct banks for electrical underground, main equipment foundation type defined (slabs, piles, etc.)* *Note that these are just the civil/structural requirements, not the actual civil/structural drawings.* *Construction knowledge and input are typically taken into account when considering the completeness of this element.*	**Not required for project.**	**The civil/structural requirements have been defined and approved by key stakeholders as a basis for detailed design.** The civil/structural requirements are nearly completely defined (with few exceptions) and documented inclusive of specifications. These documents have been issued for design (IFD) and have been approved by client / stakeholder. A detailed scope of work has been issued and contains the definition of civil / structural requirements. For some industrial projects, completing the initial 3D models is an acceptable substitute for production of design drawings.	**Most of the civil/ structural requirements are documented and are under review, but not yet approved. Stakeholders have reviewed and commented on draft documents.** Most of the civil / structural requirements are documented. The civil / structural requirements are under review.	**Some of the civil/ structural requirements have been identified but not reviewed.** The civil / structural requirements are partially developed. The civil / structural requirements have not been reviewed.	**The civil/structural requirements work has started.** Little or no meeting time or design hours have been expended on the civil / structural requirements.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	**BEST**		**MEDIUM**		**WORST**
H. CIVIL, STRUCTURAL & ARCHITECTURAL	**0**	**1**	**2**	**3**	**4**	**5**
I1. Civil/Structural Requirements (continued) ** Additional items to consider for Renovation & Revamp projects ** - Existing structural conditions (e.g., foundations, building framing, pipe racks, harmonics/vibrations, etc.) - Potential effect of noise, vibration and restricted headroom in installation of piling and on existing operations - Underground interference (utilize shallow depth designs)		All of items related to R&R (existing structural conditions, effects of noise, vibration, restricted headroom and underground interference) have been documented and approved by key stakeholders.	Most of items related to R&R (existing structural conditions, effects of noise, vibration, restricted headroom and underground interference) have been documented, but not yet approved.	Few of items related to R&R (existing structural conditions, effects of noise, vibration, restricted headroom and underground interference) have been developed.	Little or no meeting time or design hours have been expended on items related to R&R.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
I. CIVIL, STRUCTURAL & ARCHITECTURAL	**0**	**1**	**2**	**3**	**4**	**5**
I2. Architectural Requirements The following checklist should be used in defining building requirements: ☐ Building use (e.g., activities, functions) ☐ Space use programing indicating space types, areas required, and the functional relationships between spaces and number of occupants ☐ Service, storage, and parking requirements ☐ Special equipment requirements ☐ Requirements for building location/orientation ☐ Nature/character of building design (e.g., aesthetics, crime prevention through environmental design (CPTED)) ☐ Construction materials ☐ Environmentally sustainable design ☐ Interior finishes ☐ Fire resistant requirements ☐ "Safe Haven" requirements ☐ Acoustical considerations ☐ Safety, vulnerability assessment, and maintenance requirements ☐ Fire detection and/or suppression requirements ☐ Utility requirements (i.e., sources and tie-in locations) ☐ HVAC requirements ☐ Electrical requirements ☐ Power sources with available voltage & amperage ☐ Special lighting considerations ☐ Voice and data communications requirements ☐ Uninterruptible power source (UPS) and/or emergency power requirements ☐ Outdoor design conditions (e.g., minimum and maximum yearly temperatures) ☐ Indoor design conditions (e.g., temperature, humidity, pressure, air quality) ☐ Special outdoor conditions ☐ Special ventilation or exhaust requirements ☐ Equipment/space special requirements with respect to environmental conditions (e.g., air quality, special temperatures) ☐ Personnel accessibility standards (e.g., in the U.S., American with Disabilities Act requirements) ☐ Other *Comments on Issues:* *Construction knowledge and input, along with site development requirements, are typically taken into account when considering the completeness of this element.*	**Not required for project.**	**The architectural requirements have been documented and approved by key stakeholders as a basis for detailed design.** The architectural requirements are nearly completely defined (with few exceptions) and documented inclusive of specifications. These documents have been issued for design (IFD) and have been approved by client / stakeholder. A detailed scope of work has been issued and contains the definition of the requirements. For some industrial projects, completing the initial 3D models is an acceptable substitute for production of design drawings.	**Most of the architectural requirements have been documented and are under review, but not yet approved. Stakeholders have reviewed and commented on draft documents.** Most architectural requirements scope has been defined and all engineering documents to be prepared and issued have been developed. Deliverables including scope of work and specifications have been issued for review (IFR). Portions of the required documents have not yet been approved by key stakeholders.	**Some of the architectural requirements have been defined.** Architectural requirements have been identified and a draft scope of work document has been prepared.	**Architectural requirements work has started.** Work on the architectural requirements design documents has commenced. Little or no meeting time or design hours have been expended on this element.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
I. CIVIL, STRUCTURAL & ARCHITECTURAL	**0**	**1**	**2**	**3**	**4**	**5**
I2. Architectural Requirements (continued) ** Additional items to consider for Renovation & Revamp projects ** □ Consider how renovation project alters existing architectural design assumptions □ Potential reuse of existing equipment, fixtures, materials and systems for renovation project Transition plan/ swing space for people, materials and processes		All of items related to R&R have been documented and approved by key stakeholders.	Most of items related to R&R have been documented, but not yet approved.	Few of items related to R&R have been developed.	Little or no meeting time or design hours have been expended on items related to R&R.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
J. INFRASTRUCTURE	**0**	**1**	**2**	**3**	**4**	**5**
J1. Water Treatment Requirements Water treatment requirements should be documented. Items for consideration should include: □ Waste water treatment: □ Process waste □ Sanitary waste □ Waste disposal □ Storm water containment and treatment □ Other *Comments on Issues:* *Other items typically include: tanks for the water storage sized and located at the plot plan, raw water technical characteristics available for the adequate water treatment of choice. This element typically also considers other waste types such as air, fine particles, construction waste, etc.*	**Not required for project.**	**All water treatment requirements are documented and approved by key stakeholders as a basis for detailed design.** A complete water management and wastewater treatment design basis has been approved by key stakeholders including the definition of raw water supply source and quality, internal water quality requirements, waste water disposal locations and quality requirements, internal water treating processes required, storm water management, and overall water balances including normal/maximum flows and average/maximum concentrations of contaminants.	**Most of the water treatment requirements have been documented. Stakeholders have reviewed and commented on draft documents.** Most water treatment facilities have been defined and documented. Overall balances and system hydraulics are complete, with only minor adjustments anticipated. The water management and waste water treatment design basis is under review; however, the design basis has not been approved.	**Some water treatment requirements have been defined and the system configuration is being developed.** A draft water management and waste water treatment design basis has been completed. Preliminary water balances have been completed and preliminary definition of the scope of facilities has been drafted.	**Water treatment requirements are being identified.** Work (e.g., raw water availability and quality, basis rainfall volume for storm water management, overall waste water disposal requirements) has been started. A block concept for treatment facilities is being investigated.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
J. INFRASTRUCTURE	**0**	**1**	**2**	**3**	**4**	**5**
J2. Loading/Unloading/Storage Facilities Requirements A list of requirements identifying raw materials to be unloaded and stored, products to be loaded along with their specifications, and Material Safety Data Sheets. This list should include items such as: □ Instantaneous and overall loading/unloading rates □ Details on supply and/or receipt of containers and vessels □ Storage facilities to be provided and/or utilized □ Specification of any required special isolation provisions: □ Double wall diking and drainage □ Emergency detection (e.g., hydrocarbon detectors/alarms) □ Leak detection devices or alarms □ Essential security considerations should include: □ Inspection requirements □ Secure storage □ Authorized deliveries □ Access/egress control □ Other *Comments on Issues:* *Safety requirements during loading and unloading operations are defined. Construction knowledge and input us typically taken into account when considering the completeness of this element.*	**Not required for project.**	**The loading / unloading / storage facilities requirements have been defined and approved by key stakeholders as a basis for detailed design.** The loading / unloading / storage requirements are completely defined and documented inclusive of specifications. These documents have been issued for design (IFD) and have been approved by the client / stakeholder. A detailed scope of work has been issued and contains the definition for the loading / unloading / storage facilities requirements.	**Most of the loading / unloading / storage facilities requirements have been defined, documented, and are under review, but not yet approved.** Most loading / unloading / storage facilities requirements scope has been defined and all engineering documents to be prepared and issued have been developed. Deliverables including scope of work and specifications have been issued for review (IFR).	**Some of the loading / unloading / storage facilities requirements have been defined.** The loading / unloading / storage facilities requirements have been identified and a draft scope of work document has been prepared.	**Loading / unloading / storage facilities requirements work has started.** Work on the loading / unloading / storage facilities requirements design documents has commenced. Little or no meeting time or design hours have been expended on this element.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** □ Availability and access to secure storage for materials, laydown yards, etc. for R&R projects.		Availability and access to secure storage for materials, laydown yards, etc. is documented and approved.	Availability and access to secure storage for materials, laydown yards, etc. is identified, but not approved.	Availability and access to secure storage for materials, laydown yards, etc. is being identified.	Little or no meeting time or design hours have been expended on availability and access to secure storage for materials, laydown yards, etc.	

SECTION II – BASIS OF DESIGN	**Definition Level**					
	N/A	**BEST**		**MEDIUM**		**WORST**
J. INFRASTRUCTURE	**0**	**1**	**2**	**3**	**4**	**5**
J3. Transportation Requirements Specifications identifying implementation of "in-plant" transportation (e.g., roadways, concrete, asphalt, rock) as well as methods for receiving/shipping/storage of materials (e.g., rail, truck, marine) should be documented. Specifically look at detailed traffic/routing plan for oversize loads. *Comments on Issues:* *Construction knowledge and input is typically taken into account when considering the completeness of this element.*	**Not required for project.**	**Transportation requirements have been documented and approved by key stakeholders as a basis for detailed design.** The transportation requirements scope of work has been documented and approved. A logistics plan has been completed (e.g., road, rail, air or maritime access, receiving, temporary storage, heavy haul transportation routes, and weather restrictions).	**Most transportation requirements have been documented, but not yet approved.** The transportation requirements scope of work has been completed but not finalized and agreed upon by all parties. Key stakeholders have reviewed and provided comments.	**Some transportation requirements have been defined.** The transportation requirements scope of work has been drafted but has a number of open items.	**Transportation requirements have been identified and work has started.** The transportation requirements scope of work has been identified. The logistics plan may have been initiated but potential obstacles and issues have not been addressed.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** - Coordinate equipment and material movement for renovation work with Operations to ensure no unplanned impacts - Clearly identify delivery gates/docks/doors and receiving hours to be used by contractors for R&R work.		Items related to coordination with operations and material delivery have been documented and approved by key stakeholders.	Most items related to coordination with operations and material delivery have been documented, but not yet approved.	Some items related to coordination with operations and material delivery has been identified.	Little or no meeting time or design hours have been expended on items related to coordination with operations and material delivery.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
K. INSTRUMENT & ELECTRICAL	**0**	**1**	**2**	**3**	**4**	**5**
K1. Control Philosophy The control philosophy describes the general nature of the process and identifies overall control systems hardware, software, simulation, and testing requirements. It should outline items such as: □ Continuous □ Batch □ Redundancy requirements □ Classification of interlocks (e.g., process, safety) □ Software functional descriptions □ Manual or automatic controls □ Alarm conditions □ On/off controls □ Block diagrams □ Emergency shut down □ Controls startup □ Other *Comments on Issues:* *The control philosophy describes the general nature of the process as described above and should be documented in a functional specification. This is different from K2 Logic Diagrams, in that K1 Control Philosophy describes the general nature of the process, while K2 actually outlines and documents the functional descriptions of the instruments and electrical systems. Additionally, the necessary number of safety operators from a safety operation point of view has been defined. Moreover, project teams may complete a process hazards analysis (PHA). If the project team cannot reach a risk decision for a given scenario additional methods may be used such as level of protection analysis (LOPA) or hazards and operability analysis (HAZOP). Furthermore, the main system being engineered here is the basic process control system (BPCS) and all other systems are auxiliary systems interfacing with the BPCS.*	**Not required for project.**	**Control philosophy is documented and approved by key stakeholders as a basis for detailed design.** Background process descriptions are fully described. All simple and complex control loops, objectives, strategies, and functionalities are fully described. All control and safety functions pertaining to package equipment are also included based on equipment specific to the project.	**Most control philosophy requirements are documented.** Background process descriptions are fully described. Most simple control loops, objectives, strategies, and functionalities are fully described. Most complex functionalities are identified, if not fully described. Control and safety functions pertaining to package equipment are also included based on equipment specific to the project.	**Some control philosophy requirements have been developed.** Background process descriptions are fully described. Some simple control loops, objectives, strategies, and functionalities are fully described. All complex functionalities are identified, but not documented. Control and safety functions pertaining to package equipment are not available or they are based on generic equipment.	**Control philosophy requirements have been started.** Control philosophy requirements have been identified. Little or no meeting time or design hours have been expended on this topic and little or nothing has been documented.	**Not yet started.**
Additional items to consider for Renovation & Revamp projects □ Existing specifications, owner preferences and agreements, and compatibility		Existing specifications, owner preferences and agreements, and compatibility have been documented and approved.	Most existing specifications, owner preferences, agreements, and compatibility have been documented, but not yet approved.	Some existing specifications, owner preferences, agreements, and compatibility have been developed.	Little or no meeting time or design hours have been expended on existing specifications, owner preferences and agreements, and compatibility.	

SECTION II –BASIS OF DESIGN	Definition Level					
	N/A	**BEST**		**MEDIUM**		**WORST**
K. INSTRUMENT & ELECTRICAL	**0**	**1**	**2**	**3**	**4**	**5**
K2. Logic Diagrams Logic diagrams should be developed and provide a method of depicting interlock and sequencing systems for the startup, operation, alarm, and shutdown of equipment and processes. *Comments on Issues:* *Logic diagrams are meant to offer functional descriptions and control narratives of the instruments and electrical systems.*	**Not required for project.**	**The logic diagrams have been documented and approved upon by key stakeholders as a basis for detailed design.** The logic diagrams have been documented and approved by key stakeholders. All safety instrumented functionalities (SIF's) are fully documented and have undergone process hazards analysis (PHA)	**Most of the logic diagrams have been documented and are under review, but not yet approved.** Most logic diagrams are issued for process hazards analysis (PHA) and review. All SIF's are fully described.	**Some of the logic diagrams have been documented with holds for deficiencies.** Some logic diagrams have been fully documented; however, there are holds for deficiencies. Nothing has been issued for review. All SIF's are developed.	**The logic diagrams have been identified and some initial thoughts have been applied to this effort.** Logic diagrams have been identified. Little or no meeting time or design hours have been expended on this topic and little or nothing has been documented.	**Not yet started.**
Additional items to consider for Renovation & Revamp projects - Field verify logic diagrams to ensure they are correct and has been maintained to reflect the actual or current operating scenarios.		Field verification of the logic diagrams to ensure they are correct or have been maintained to reflect the actual or current operating scenarios has been document and approved.	Field verification has been completed for most of the logic diagrams and has been documented, but not yet approved.	Field verification has been completed for some of the logic diagrams and has been documented, but nothing has been issued for approval.	Little or no meeting time or design hours have been expended on the field verification of the logic diagrams.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
K. INSTRUMENT & ELECTRICAL	**0**	**1**	**2**	**3**	**4**	**5**
K3. Electrical Area Classifications The electrical area classification plot plan is provided to show the environment in which electrical and instrument equipment is to be installed. This area classification will follow the guidelines as set forth in the latest code requirements (for example, the National Electric Code in the U.S.). Installation locations should include the following: □ General purpose □ Hazardous □ Class I: Gasses and vapors □ Class II: Combustible dusts □ Class III: Easily ignitable fibers □ Corrosive locations □ Other	**Not required for project.**	**Electrical area classifications have been approved by the process hazards analysis (PHA) team and key stakeholders as a basis for detailed design.** Hazardous area classification drawings are based on completed equipment arrangement drawings including boundaries with dimensions, calculations, legend sheets and associated process information. Consideration has been made for operating facilities with classified areas, location of proposed high voltage outdoor substations relative to nearby classified areas, and nearby public areas. Ventilation systems, air inlets, exhausts for turbines and engines, and ventilation systems that affect the area classification are highlighted. Special barriers / walls intended for changing area classifications or separating areas with different classifications are identified. Roadways / routes that may impact area classification clearly shown with access requirements for roads / driveways approved by operations.	**Most electrical area classifications are documented and are under review, but not yet approved.** Hazardous area classification drawings are based on current equipment arrangement drawings including boundaries with dimensions, calculations, legend sheets, and associated process information. Consideration has been made for operating facilities with classified areas, location of proposed high voltage outdoor substations relative to nearby classified areas, and nearby public areas. Ventilation systems, air inlets, exhausts for turbines and engines, and ventilation systems that affect the area classification are highlighted. Special barriers / walls intended for changing area classifications or separating areas with different classifications are identified. Roadways / routes that may impact area classification clearly shown with access requirements for roads / driveways are documented.	**Some electrical area classifications have been developed with holds for deficiencies.** Hazardous area classification drawings are based on current but incomplete equipment arrangement drawings with some holds on major equipment including boundaries with dimensions and legend sheets. All process information not yet available to define classifications. Some consideration made for operating facilities with classified areas, location of proposed high voltage outdoor substations relative to nearby classified areas, and nearby public areas. Ventilation systems, air inlets, exhausts for turbines and engines, and ventilation systems that affect the area classification mostly highlighted. Special barriers / walls intended for changing area classifications or separating areas with different classifications largely identified. Roadways / access routes are preliminary but have been discussed with operations.	**Electrical area classifications work has started.** Identification of electrical classification has started using major columns and vessels along with assumed process information. Little or no design hours have been expended on electrical area classification and little has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** □ Reclassification impact on existing access and operating areas		Reclassification impact on existing access/operating areas have been documented and approved.	Most reclassification impact on existing access/operating areas has been documented, but not yet approved.	Some reclassification impact on existing access/operating areas has been developed.	Little or no design hours have been expended on reclassification impact on existing access/operating areas.	

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
K. INSTRUMENT & ELECTRICAL	**0**	**1**	**2**	**3**	**4**	**5**
K4. Substation Requirements/Power Sources Identified Substation requirements / power sources identified. Substation requirements should be documented and may include the following: □ Number of substations required □ Electrical equipment rating required for each substation □ Specifications for all major electrical substation equipment □ Infrastructure required for each substation considering building type and environment, fencing, access, lighting and barriers, and substation yard materials Clearly define power sources for the project in relation to: □ Location, voltage level, available power □ Electrical equipment available □ Electrical ratings and routes of power feeds from their sources to the project substations □ Specifications for special power sources should be described and provided (e.g., emergency generators or in-plant generation) □ Temporary construction power sources *Comments on Issues:* □ Electrical distribution type defined; above ground or underground requirements □ Compliance with safety codes and standards	**Not required for project.**	**Substation requirements / power sources have been documented and approved by key stakeholders as a basis for detailed design.** Electrical sources and tie-in points are documented with cable routing methods defined and routing plan approved by operations. Environmental implications and requirements are completely understood. Number, size, and locations of substations are clearly defined; substations shown on area classification drawings and approved by operations. Transformer locations identified. Substation area access/egress identified with regard to construction, maintenance and fire protection needs. Substation base elevation defined and construction method identified (packaged, modular, or stick built). Temporary power sources/facilities and locations identified. Requirements for cutovers is known, documented and approved by operations.	**Identification of most substation requirements / power sources is complete and under review, but not yet approved.** Most electrical sources with tie-in points are identified and reserved with cable routing methods being largely defined and routing plan approved by operations. Environmental implications and requirements are completely understood. Number, size, and locations of substations are mostly defined and identified on area classification drawings. Transformer locations identified. Substations area access/egress identified with regard to construction, maintenance and fire protection needs. Construction method identified (packaged, modular, or stick built). Requirements for cutovers largely known, and under review by operations.	**Some substation requirements / power sources are identified.** Some electrical sources with tie-in points identified and preliminary cable routing plan discussed with operations but not yet approved. Environmental implications and requirements somewhat understood. Number and locations of substations largely defined and sizes assumed with preliminary operations buy-in. Preliminary transformer locations have been documented. Construction method has been identified (packaged, modular, or stick built).	**Substation requirements / power sources identification work has started.** Tie-in points are not known or are assumed and preliminary cable routing not approved by operations. Environmental implications and requirements assumed. Number and locations of substations is preliminary and not yet approved by operations. Substation sizes are assumed and identified on area classification drawings. Transformer locations are preliminary.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
K. INSTRUMENT & ELECTRICAL	**0**	**1**	**2**	**3**	**4**	**5**
K4. Substation Requirements/Power Sources Identified (Continued) ** Additional items to consider for Renovation & Revamp projects ** ☐ Impact on existing and new equipment selection (e.g. short circuit ratings) ☐ Field verify condition of isolation points ☐ Sequencing of tie-ins with production planning to ensure safety and on-going operations ☐ Tie in points approved by Operations ☐ Ensure and conduct a structured process to validate tie-ins and tie-in strategy. ☐ Ensure new electrical systems or equipment are compatible with industrial environment (e.g., uninterrupted power supplies, inverters.)	**Not required for project.**	All applicable items related to impact, field verification, sequencing, and tie-ins have been documented and approved.	Most of the items related to impact, field verification, sequencing, and tie-ins have been documented, but not yet approved.	Some items related to impact, field verification, sequencing, and tie-ins have been developed.	Little or no meeting time or design hours have been expended on items related to impact, field verification, sequencing, and tie-ins.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
K. INSTRUMENT & ELECTRICAL	**0**	**1**	**2**	**3**	**4**	**5**
K5. Electric Single-Line Diagrams A single line diagram indicates the components, devices, or parts of an electrical power distribution system. Single line diagrams are intended to portray the major system layout from the public utility's incoming transmission line to the motor starter bus. Depending on the size of the electrical system, the single line diagrams should include several levels of distribution such as: - Incoming utility with owner substation/distribution to high and medium voltage motors and substations - Unit substations and switchgear - Motor control centers with distribution to motors, lighting panels	**Not required for project.**	**Electric single-line diagrams are documented and approved by key stakeholders as a basis for detailed design.** Key one-line diagram of the entire power distribution system with references to more detailed one-line diagrams is complete in accordance with the Electrical Control Philosophy including legends or symbol sheets. Name tags or labels for all equipment are documented. Equipment information and details sufficient to build models for preliminary load flow and short circuit studies are documented. All power sources with voltage and available short circuit currents including utility connections and generators are available.	**Most electric single-line diagrams are complete and under review, but not yet approved.** Key one-line diagram of the entire power distribution system with references to more detailed one-line diagrams is complete in accordance with the Electrical Control Philosophy including legends or symbol sheets. Name tags or labels for most equipment are documented. Most equipment information and details sufficient to build models for preliminary load flow and short circuit studies are documented. Most power sources with voltage and available short circuit currents including utility connections and generators.	**Some electric single-line diagrams are developed with holds for deficiencies.** Key one-line diagram of entire power distribution system with references to more detailed one-line diagrams are being developed in accordance with the Electrical Control Philosophy including legends or symbol sheets. Name tags or labels for some equipment are documented.	**Electric single-line diagrams work has started.** The key one-line diagram of the entire power distribution system has been started and only includes major equipment. Equipment information and details sufficient to build models for preliminary load flow and short circuit studies is not available.	**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
L. INSTRUMENT & ELECTRICAL	**0**	**1**	**2**	**3**	**4**	**5**
K5. Electric Single-Line Diagrams (Continued) *Comments on Issues:* □ Single-line diagrams identify all feeding levels of the unit consumers □ Based on the electrical single-line diagrams, the electrical load list will be defined	**Not required for project.**	Capacity, voltages, impedances, connections and grounding method of transformers are documented. Circuit breaker and fuse sizes are listed. Capacity and short circuit ratings of switchgear and motor control centers (MCC's) are documented. Sizes and number of conductors for feeders and cables are listed. Low voltage MCC's are fully developed with breaker size and equipment numbers. All motors >100 horse power (HP) fed directly from switchgear are shown individually. All system grounding, generator, and transformer neutral grounding is documented. Future power sources and loads are documented. Capacity and short circuit information is supported by calculations and power system studies. Protective relaying and metering (including potential and current transformers) is documented on separate relaying and metering one-line drawings.	Capacity, voltages, impedances, connections and grounding method of transformers are documented. Circuit breaker and fuse sizes are listed. Capacity and short circuit ratings of switchgear and motor control centers (MCC's) are documented. Most sizes and number of conductors for feeders and cables are listed. Low voltage MCC's are largely assumed or lumped. Most motors >100 horse power (HP) fed directly from switchgear are individually identified. All system grounding, generator, and transformer neutral grounding is documented. Future power sources and loads are documented. Capacity and short circuit information is supported by calculations and power system studies. Protective relaying and metering schemes are not complete.	Some equipment information and details sufficient to build models for preliminary load flow and short circuit studies are developed. All power sources with voltage and available capacity are identified. Short circuit currents are preliminary, or availability is assumed. Voltages of transformers are known but sizes not defined. Capacity and short circuit ratings of switchgear and MCC's are preliminary. Feeder sizes are preliminary. Low voltage MCC's are lumped loads. Motors >100 HP and fed directly from switchgear are individually identified. All system grounding, generator, and transformer neutral grounding are identified. Future power sources and loads are unknown. Protective relaying and metering schemes are not developed.		**Not yet started.**

SECTION II – BASIS OF DESIGN	Definition Level					
	N/A	BEST		MEDIUM		WORST
K. INSTRUMENT & ELECTRICAL	**0**	**1**	**2**	**3**	**4**	**5**
K6. Instrument & Electrical Specifications Specifications for instrument and electrical systems should be developed and should include items such as: ☐ Distributed Control System (DCS) ☐ Instrument data sheets ☐ Motor control and transformers ☐ Power and control components ☐ Power and control wiring (splicing requirements) ☐ Cathodic protection ☐ Lightning protection ☐ Security systems ☐ Grounding ☐ Electrical trace ☐ Installation standards ☐ Lighting standards ☐ Civil requirements for electrical installation: ☐ Protection/warning for underground cabling ☐ Special slabs or foundations for electrical equipment ☐ Concrete-embedded conduit ☐ Other *Comments on Issues:* *Specifications generally have not been developed for the following: instrument datasheets; loop diagrams; and fire protection at the end of FEED.*	**Not required for project.**	**Instrument and electrical specifications are documented and approved by key stakeholders as a basis for detailed design.** Instrument and electrical specifications have been developed and include the DCS; power requirements; power and control components; grounding; preliminary major inline instrument identification; general installation standards; motor control centers (MCC's) and transformers; electrical cable; civil requirements; major fiber optic cable layout; inputs and outputs (I/O). Main power infrastructure components may be on order. Specifications have been documented for the following: installation standard details, including lighting standards; lightning protection; cathodic protection; electrical trace; and security systems.	**Most instrument and electrical specifications are documented and under review, but not yet approved.** Instrument and electrical specifications have been developed and are under review. They include the DCS; power requirements; power and control components; grounding; preliminary major inline instrument identification; general installation standards; MCC's and transformers (with minor holds) and electrical cable. Some minor issues may not be defined. Main power infrastructure components may be on order. Most specifications have been developed for the following installation standard details including: civil requirements; major fiber optic cable layout; detail installation standards; I/O (with holds); lighting standards and protection. Specifications have generally not been documented for: cathodic protection; electrical trace; and security systems.	**Some instrument and electrical specifications are developed.** Some instrument and electrical specifications have been developed for the DCS; power requirements; power and control components; grounding; preliminary inline instrument identification; general installation standards; MCC's and transformers (with significant holds); and electrical cable. Long lead main power infrastructure components may be on order. Preliminary specifications have been developed with some deficiencies for civil requirements; major fiber optic cable layout; detail installation standards; and I/O (with holds). Specifications have not been developed for: lighting standards; lightning protection; cathodic protection; electrical trace; and security systems.	**Instrument and electrical specifications development work has started.** Instrument and electrical specification requirements have been developed for the DCS; power requirements; power and control components; grounding; preliminary inline instrument identification; general installation standards. Little or no meeting time or design hours have been expended on additional specification development.	**Not yet started.**

SECTION III: EXECUTION APPROACH

This section consists of elements that should be evaluated for a full understanding of the owner's strategy and required approach for executing the project construction and closeout.

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
L. PROCUREMENT STRATEGY	**0**	**1**	**2**	**3**	**4**	**5**
L1. Identify Long Lead/Critical Equipment and Materials Identify engineered equipment and material items with lead times that will impact the detailed engineering for receipt of vendor information or impact the construction schedule with long delivery times. *Comments on Issues:* *Approval of advance funding may be required for long lead/critical equipment and materials before the project's phase 3 funding request is submitted in order to meet schedule deadlines.*	**Not required for project.**	**Long lead/critical equipment and materials have been identified. Relevant procurement and technical documentation has been prepared and is approved by key stakeholders (e.g., project management, operations and maintenance, business unit). It has been formally issued and is consistent with the project schedule.** Purchase orders have been formally issued (with cancellation clauses) or are ready to be issued, as per project schedule, and include delivery and materials that meet project requirements in terms of specifications and schedule. To support the project schedule, the required technical information and quotations from vendors have been received to complete the front end engineering design (FEED).	**Long lead/critical equipment and materials have been identified; relevant procurement and technical documentation has been prepared. As the procurement plan is not fully approved, formal issue of purchase orders is pending for some equipment and/or materials.** Some purchase orders have been formally issued (with cancellation clauses) or are ready to be issued, as per project schedule. These include delivery dates and materials that meet project requirements in terms of specifications, schedule, and quotations from the potential suppliers, including technical information.	**Some of the long lead/critical equipment and materials have been identified, and some development activity performed with open items.** The activities for securing identification of the long lead/critical equipment and materials have several issues that require additional work to resolve. These issues may include ensuring that delivery dates coincide with the project schedule, advance funding requirements, or receiving necessary technical information from vendors to support the production of detailed engineering and design.	**Some of the long lead/critical equipment and materials have been identified.** Initial thoughts have been applied to identifying the long lead/critical equipment and materials. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** □ Identification and delivery of long lead / critical equipment and materials are especially important for shutdowns / turnarounds. □ Delivery dates must be identified in advance of shutdown / turnarounds to support preparations for pre-outage activities		The R&R long lead/critical equipment and materials have been approved and delivery dates set in advance of shutdowns / turnarounds, establishing procurement and purchasing schedules. The purchase orders have been issued with cancellation clauses.	The R&R long lead/critical equipment and materials have been identified and delivery dates set in advance of shutdowns / turnarounds. Activities for the delivery of the balance of equipment and material are under finalization.	Some of the R&R items related to the long lead/critical equipment and materials have been identified and are being assessed, including identifying delivery dates in advance of shutdowns / turnarounds, establishing procurement and purchasing schedules.	Little or no meeting time or development hours have been expended on R&R items related to the long lead/critical equipment and materials.	

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	**BEST**		**MEDIUM**		**WORST**
L. PROCUREMENT STRATEGY	**0**	1	**2**	**3**	**4**	**5**
L2. Procurement Procedures and Plans Specific guidelines, special requirements, or methodologies for accomplishing the purchasing, expediting, delivery, and security of equipment and materials required for the project. Evaluation criteria should include: ☐ Listing of approved vendors ☐ Client or contractor paper ☐ Reimbursement terms and conditions ☐ Guidelines for supplier alliances, single source, or competitive bids ☐ Guidelines for engineered/field contracts ☐ Responsibility for owner-purchased items: ☐ Financial ☐ Shop inspection ☐ Expediting ☐ Tax strategy: ☐ Engineered equipment ☐ Field materials ☐ Labor ☐ Write-offs of existing facilities and equipment ☐ Definition of source inspection requirements and responsibilities ☐ Definition of traffic/insurance responsibilities ☐ Definition of procurement status reporting requirements ☐ Additional/special owner accounting requirements ☐ Definition of spare parts requirements, including consideration to match existing ☐ Local regulations (e.g., tax restrictions, tax advantages) ☐ Other *Comments on Issues:* *In many issues, approval requirements must be defined, including what approvals are needed and by whom at each phase of the process (e.g., data sheets, inquiry package, bid tabs, purchase requisitions, and vendor data). The duration of each approval needs to be agreed upon. Source inspection typically should address cyber security.*	**Not required for project.**	**The procurement procedures and plans have been documented and approved by the key stakeholders (e.g., the business unit, project management).** The procurement procedures and plans include roles and responsibilities practices and procedures, purchasing plans for equipment, fabricated items (pipe and steel), bulk materials, spare parts and specific strategies for contracting, expediting and quality assurance/quality control which includes methods for inspection, analytical testing, and logistics. A budget and schedule for the procurement plan have been established, including any anticipated delays to the master schedule.	**Most of the procurement procedures and plans are documented and under review, but not fully approved.** The procurement procedures and plans have minor issues that need to be addressed such as completely defining roles and responsibilities or practices and procedures, or adjusting the master schedule based on the anticipated vendor delays and logistics studies.	**Some of the procurement procedures and plans have been developed with open items.** The procurement procedures and plans have several issues that require resolution. These may include issues related to the roles and responsibilities (who provides what), practices and procedures, or issues regarding any of the strategies employed on the project. For instance, the vendor list is under development and procurement procedures and plans are not complete regarding inspections, expediting and logistics.	**Some items included in the procurement procedures and plans have been identified.** Initial thoughts have been applied to identifying items in the procurement procedures and plans; however, these have not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
M. PROCUREMENT STRATEGY	**0**	1	**2**	**3**	**4**	**5**
L2. Procurement Procedures and Plans (continued) ** Additional items to consider for Renovation & Revamp projects ** □ Procedures for repair, refurbishment, and relocation of existing equipment Retrofit kits (e.g., non-standard connections and obsolete equipment may require adaptors)	**Not required for project**	The procurement procedures and plans have been documented and approved, including procedures for repair, refurbishment, and relocation of existing equipment and retrofit kits.	Most of the R&R items related to the procurement procedures and plans have been documented and are under review.	Some of the R&R items related to the procurement procedures and plans have been identified; for instance, assessing procedures for repair, refurbishment, and relocation of existing equipment and retrofit kits.	Little or no meeting time or development hours have been expended on R&R items related to the procurement procedures and plans.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
L. PROCUREMENT STRATEGY	**0**	**1**	**2**	**3**	**4**	**5**
L3. Procurement Responsibility Matrix A procurement responsibility matrix has been developed showing authority and responsibility for procurement. This matrix should outline responsibilities for: ☐ Engineering and design ☐ Engineered equipment ☐ Construction ☐ Bulk materials ☐ Fabrication/modularization ☐ Consulting services ☐ Commissioning and startup materials ☐ Source inspection ☐ Other *Comments on Issues:* *The responsibility matrix should tie to project controls (i.e., budget approval, bid evaluations, technical approvals, etc.)*	**Not required for project.**	**The procurement responsibility matrix has been documented and approved by the key stakeholders (e.g., the business unit, project management, operations and maintenance).** A well-defined procurement responsibility matrix is in place that shows authority and responsibility for procurement and approval thresholds. The matrix specifically addresses responsibilities for engineering and design, engineered equipment, construction, bulk materials, fabrications/modularization, consulting services, commissioning and startup materials and source inspection.	**Most of the procurement responsibility matrix has been documented and is under review, but not fully approved.** The procurement responsibility matrix has minor issues that need to be addressed such as any possible shifting of responsibilities between stakeholders or alignment of responsibilities.	**Some of the procurement responsibility matrix has been developed with open items.** The procurement responsibility matrix has several issues that require resolution such as specific responsibilities related to bulk materials or engineered equipment, fabricated items (e.g., pipe and steel, long lead valves, source inspection, start-up and operational spare parts, etc.)	**Some items to be included in the procurement responsibility matrix have been identified.** Initial thoughts have been applied to identifying items in the procurement responsibility matrix; however, these have not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Utilization of reused and existing equipment, materials, lines, electrical and instrumentation, etc. ☐ Availability of procurement support during time-constrained R&R work, especially where expedited material services are required		The procurement responsibility matrix has been documented and approved, including the utilization of reused and existing equipment, materials, lines, electrical and instrumentation and the availability of procurement support during time constrained R&R work.	Most of the R&R items related to the procurement responsibility matrix have been documented and are under review.	Some of the R&R items related to the procurement responsibility matrix have been identified, including assessing the utilization of reused and existing equipment, materials, lines, electrical and instrumentation and the availability of procurement support during time constrained R&R work.	Little or no meeting time or development hours have been expended on R&R items related to the procurement responsibility matrix.	

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	**BEST**		**MEDIUM**		**WORST**
M. DELIVERABLES	**0**	**1**	**2**	**3**	**4**	**5**
M1. CADD/Model Requirements Computer Aided Drafting and Design (CADD) requirements should be defined. Evaluation criteria should include: ☐ Application software preference (e.g., 2D or 3D CADD, application service provider (ASP)), including licensing requirements ☐ Configuration and administration of servers and systems documentation defined ☐ For 3D CADD, go/no-go on walk-through simulation for operations checks, interference checks, and construction planning and scheduling ☐ Owner/contractor standard symbols and details ☐ Handling of life cycle facility data including asset information, models, and electronic documents ☐ Information technology infrastructure to support electronic modeling systems, including uninterruptible power systems (UPS) and disaster recovery ☐ Security and auditing requirements defined ☐ Physical model requirements ☐ Other *Comments on Issues:* *The deliverable of this element is a CADD/model requirements plan that informs detailed design and construction. The plan typically would include the application software to be compatible for transferring knowledge between construction and the operations and maintenance groups. It would include the configuration of servers and systems. It would also address the handling of life-cycle facility data, metadata, information technology infrastructure, security and auditing requirements. Requirements for physical models and walk-through simulations should also be considered.* *If this is an R&R project, evaluate whether existing models are available or whether existing systems need to be mapped. The need to 3D laser scan existing facilities should be considered.*	**Not required for project.**	**CADD/model requirements have been documented in a plan and approved by key stakeholders (e.g., the project team, the engineering contractor, and the operations, maintenance and construction groups).** The CADD/model requirements are well defined and include the following: software used on the project has been defined, software licenses have been obtained, the level of detail shown on the CADD generated drawings is agreed upon and is compatible with the engineering and construction requirements, building information modeling (BIM) / 4D CADD requirements have been defined for fabrication and construction, the CADD usage for detailed engineering has been determined, model reviews, deliverables and timing have been established, servers and systems are configured and are operating. A plan for transfer of custody of the CADD, drawings, documentation and meta-data from the project to operations and maintenance has been established. A method for measuring the CADD/Model progress is defined and agreed upon.	**Most of the CADD/model requirements are documented in a plan and under review, but not fully approved. The software platform has been chosen.** The CADD/model requirements have minor issues that need to be resolved. These could include obtaining final software licenses, or identification of the level of model detail to be used. Initial agreement on model handover and construction support have been established. The method for measuring CADD/model progress is under review.	**Some of the CADD/model requirements are developed with open items.** The CADD/model requirements have several issues that require resolution such as determination of software to use, obtaining software licenses or determining model review deliverables. Some consideration has been made to identify the requirements to support fabricators and construction.	**Some items to be included in the CADD/model requirements have been identified but nothing has been documented.** Initial thoughts have been applied to identifying items in the CADD/model requirements; however, these have not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
M. DELIVERABLES	**0**	**1**	**2**	**3**	**4**	**5**
M2. Deliverables Defined The following items should be included in a list of deliverables: ☐ Drawings ☐ Project correspondence ☐ Project Process Safety Management (PSM) documents ☐ Permits ☐ Project data books (quantity, format, contents, and completion date) ☐ Equipment folders (quantity, format, contents, and completion date) ☐ Design calculations (quantity, format, contents, and completion date) ☐ Spare parts special forms ☐ Loop folder (quantity, format, contents, and completion date) ☐ Procuring documents ☐ Isometrics/field erection details ☐ As-built documents ☐ Quality assurance documents ☐ Other *Comments on Issues:* *Some organizations consider this deliverables list to be a compilation of closeout requirements documents. The deliverables list becomes part of the engineering estimate basis. Handover requirements for each type of deliverable must be clearly defined, including associated meta-data requirements. Deliverables should be reviewed to help define fit for purpose.*	**Not required for project.**	**The list of deliverables needed for the project has been documented and approved by the key stakeholders (e.g., engineering, operations and maintenance, project management, construction).** The list of deliverables is documented and approved. Requirements for sets of deliverables presented as work packages to construction, operations and maintenance (e.g., project data books, equipment files, purchase order files, and "as-built" drawings) have been established and meta-data requirements defined. Media used for delivering documents has been established (e.g., type of electronic media, server, web site, e-mail, hard copy, etc.). A budget and schedule have been established to address the deliverables. The list of deliverables is discipline specific with expected quantities.	**Most of the items in the list of deliverables for the project have been documented and the list is under review, but not fully approved.** The list of deliverables has minor issues that require resolution such as requirements for format/sets of deliverables to be presented as work packages, meta-data requirements, or media used for delivering documents. A budget and schedule to address the deliverables are being completed.	**Some of the deliverables needed for the project have been identified and organized in a list, with open items.** The list of deliverables is under development and has several issues that require resolution such as requirements for sets of deliverables presented as work packages, project data books, equipment files, purchase order files, "as-built" drawings, or media used for delivering documents.	**Some initial thought has been given to the required deliverables but nothing has been documented.** Initial thoughts have been applied to identifying the list of deliverable needs; however, these have not been applied to the project. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
M. DELIVERABLES	**0**	**1**	**2**	**3**	**4**	**5**
M2. Deliverables Defined (Continued) ** Additional items to consider for Renovation & Revamp projects ** □ Requirements to update existing (legacy) documentation / models and as-built drawings, including equipment folders/asset management systems □ Procedures for retiring an asset including the documentation requirements, spare parts inventory, and accounting requirements	**Not required for project**	The list of R&R deliverables has been documented and approved, including requirements to update existing (legacy) documentation/models and as-built drawings, including equipment folders/asset management systems and procedures for retiring assets.	Most of the R&R items related to the list of deliverables have been documented and are under review.	Some of the R&R items related to the list of deliverables have been identified and are being assessed, including requirements to update existing (legacy) documentation/models and as-built drawings, equipment folders/asset management systems and procedures for retiring assets.	Little or no meeting time or development hours have been expended on items related to R&R deliverables.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
M. DELIVERABLES	**0**	**1**	**2**	**3**	**4**	**5**
M3. Distribution Matrix A distribution matrix (document control system) should be developed that identifies most correspondence and all deliverables. It denotes who is required to receive copies of all documents at the various stages of the project, and ensures the proper distribution of documentation. Some documents may be restricted due to proprietary nature. *Comments on Issues:* *The criteria that regulate relationships between the parties (e.g., organization, numbering/coding, communication, correspondence & meeting procedure, establishing an electronic document exchange via secure folder, etc.) are typically developed. This includes defining criteria for the types of correspondence (e.g., letters, electronic mail, notes of meetings, and telephone notes of conversations, transmittals, and templates for forms to be used for such communications).* *Document control typically utilizes a computerized document control process that provides up-to-date approval, status, and tracking of revision controlled documents, with controlled distribution to all parties involved in the project. A formal feedback process is typically used for reviewing comments and additions along with a "lessons learned" register for continual improvement of documents.* *The distribution matrix should be reviewed to help define fit for purpose.*	**Not required for project.**	**The distribution matrix for all document types is complete and has been approved by the key stakeholders (e.g., project team, construction, and operations and maintenance).** The distribution matrix outlines the documents that are to be prepared for the project, the classification of each document by discipline, who is to receive each document, and what the responsibilities of the participants are with each of the documents (e.g., originator, approver, reviewer, information only, etc.). A plan has been created to review and update the distribution matrix on an agreed upon frequency.	**The distribution matrix for most of the document types is complete and is under review, but not fully approved.** The distribution matrix has minor issues that need to be addressed such as the final list of documents prepared for the project, final classifications of documents by discipline or final responsibilities for each document.	**The distribution matrix for some of the document types has been developed with open items.** The distribution matrix has several issues that require resolution such as critical documents not being included in the matrix, documents not having full distribution information, documents not being fully classified by discipline and type, or other essential information such as correspondence procedures or technical communication requirements.	**Some of the document types to be included in the distribution matrix have been identified but nothing has been documented.** Initial thoughts have been applied to identifying the list of documents to be included in the distribution matrix; however, no list has been started.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
N. PROJECT CONTROL	**0**	**1**	**2**	**3**	**4**	**5**
N1. Project Control Requirements A method for measuring and reporting progress should be established and documented. Evaluation criteria should include: - Change management procedures, including interface with information systems - Cost control procedures - Schedule/percent complete control procedures - Cash flow projections - Report requirements - Other *Comments on Issues:* *Information that is typically considered as part of the completeness of this element include requirements such as roles and responsibilities, planning and scheduling details, progress tracking, project cost analysis and cost control monitoring, change and scope management procedures including asset management of change (MOC) and project change orders, software to be utilized and file types to be transmitted. The team may want to consider the extent of project control including when project control ends for the project.* *A critical input to project control requirements is to have an effective cost estimate (for example, one that supports a +/- 10% cost estimate, or an AACEi Class 3 cost estimate) that includes design, construction/demolition, professional service, contingency, startup and commissioning and so forth. Effective front end engineering design informs good cost estimates.*	**Not required for project.**	**Project control requirements have been documented and approved by the key stakeholders (e.g., the business unit, project management, construction, and engineering).** The project control requirements include fully developed narratives for cost reporting procedures, scheduling and monitoring controls, cost and schedule forecasting, monthly reporting requirements, change and scope management procedures, progress tracking, invoicing and payment procedures, and work breakdown structure requirements. A budget and schedule have been established for project controls activities.	**Most of the project control requirements are documented and under review, but not fully approved.** The project control requirements have minor issues that require further definition. These may include final cost reporting procedures such as cash flow curves, final cost comparison procedures, final change order processing forms, or other minor issues that can be easily resolved.	**Some of the project control requirements have been developed with open items.** The project control requirements have several issues that require resolution such as cost reporting procedures for billing and invoice validation, a developed systematic process for monitoring all project forecasting costs, a standardized work breakdown structure, or other issues.	**Some of the project control requirements have been identified but nothing has been documented.** Initial thoughts have been applied to identifying the project control requirements; however, there are numerous project control procedures yet to be developed. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
N. PROJECT CONTROL	**0**	**1**	**2**	**3**	**4**	**5**
N1. Project Control Requirements (Continued) ** Additional items to consider for Renovation & Revamp projects ** ☐ Detailed hourly schedule ☐ Additional communication to coordinate contractor activities with existing owner maintenance & plant operations ☐ Clearly defined outage dates and constraints ☐ Integration of multiple projects ☐ Change management procedures (CMP)		Project control requirements for R&R items have been documented and approved, including a detailed schedule, coordination with existing owner and plant operations, outage dates, integration of multiple projects and change management procedures.	Most of the project control requirements for R&R items have been documented and are under review. A detailed schedule is complete and coordination has occurred with operations and maintenance. Minor turnaround scope packages included in outage are still being finalized, project overlaps have been identified, change management procedures are complete.	Some of the project control requirements for R&R items have been identified and are being assessed, including a detailed schedule, coordination with existing owner and plant operations, integration of multiple projects and change management procedures. Outage dates have been assigned nominally to a quarter of a specific year.	Little or no meeting time or development hours have been expended on the project control requirements for R&R items. Outage dates are not known.	

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
N. PROJECT CONTROL	**0**	**1**	**2**	**3**	**4**	**5**
N2. Project Accounting Requirements Project specific accounting requirements have been identified and documented. These requirements include items such as: □ Financial (client/regulatory) □ Phasing or area sub-accounting □ Capital vs. non-capital □ Report requirements □ Payment schedules □ Other *Comments on Issues:* *Other information that is typically considered as part of the completeness of this element include: an approved code of accounts (COA) and a formal system to track and report accounts, division of accounts to manage different aspects of the project, specific criteria for capital vs. non-capital equipment items, standard reporting format for schedules, contingency release plan, and approved payment schedule and associated procedures.*	**Not required for project.**	**The project accounting requirements are documented and approved by the key stakeholders (e.g., the business unit, project management, and the accounting/financial group).** The project accounting requirements include procedures for invoice processing and payment, use of specific systems to track costs, and project close out procedures (e.g., accounting and financial procedures). The level of authorization for payments and the related responsibilities for approving and releasing payments are defined and agreed upon.	**Most of the project accounting requirements are documented and under review, but not fully approved.** The project accounting requirements have minor issues that require further definition. These may include, final procedures for invoice processing, a detailed COA tied to the work breakdown structure (WBS), a final list of capital vs. non-capital equipment or other minor issues. A few individuals involved in receiving and authorizing payments and financial decisions are still being identified.	**Some of the project accounting requirements have been developed with open items.** The project accounting requirements have a number of issues that require resolution. These may include defining invoice processing and payment requirements, developing project closeout procedures or establishing systems to track costs. Individuals responsible for the invoices and payment procedures are not identified.	**Some of the project accounting requirements have been identified but nothing has been documented.** Initial thoughts have been applied to identifying the project accounting requirements; however, there are numerous accounting procedures that have yet to be developed. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
N. PROJECT CONTROL	**0**	**1**	**2**	**3**	**4**	**5**
N3. Risk Analysis A risk analysis focusing on cost and schedule has been performed and a process is in place to ensure periodic risk analysis is conducted. Major project risks need to be identified, quantified, and management actions taken to mitigate problems. Pertinent issues may include risks in terms of: ☐ Design ☐ Construction ☐ Management ☐ Business ☐ Operational impact ☐ Other *Comments on Issues:* *Use of risk analysis, otherwise known as a risk management plan, can provide a basis for developing contingency for cost and schedule estimates. Typically, a risk management plan is used throughout the project lifecycle, with some risks continuing to be identified while others are retired. Among the many other items that might affect cost and schedule are: safety, environment, community, government/agency permits, construction resources, building trades labor, heavy haul and lift, hazardous operations, and congested areas due to overlapping maintenance and project work.*	**Not required for project.**	**The risk analysis and mitigation program and plan have been documented and approved by key stakeholders (e.g., the business unit, engineering, project management, operations and maintenance, construction groups).** Risk analyses have already been performed prior to FEP phase gate 3. The approved risk analysis program includes procedures for identification of risks, evaluation of risks, risk mitigation strategies, and an assignment of the individuals responsible for the risk mitigation, implementation and monitoring of the risk mitigation program. A budget and schedule have been established for risk analysis along with the work process to maintain, add, and retire risks throughout the project.	**A risk analysis and mitigation program and plan has been documented but not yet approved.** The plan is mostly in place with some minor issues still to be considered (e.g., budget responsibility for risk analysis, review of mitigation plans, detailed assessment for some identified risks). Risk analyses have already been performed prior to FEP phase gate 3.	**Some of the risk analysis and mitigation program has been developed with open items.** The risk analysis and mitigation program has several issues that require resolution. These may include the identification of major risks along with appropriate mitigation measures for each risk or the identification of other major and minor risks on the project. An integrated risk mitigation plan has not been developed.	**Some of the major risks for the project have been identified but nothing has been documented.** Initial thoughts have been applied to identifying the risk analysis and mitigation program; however, there are numerous risk analysis procedures that have nothing developed. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**
** Additional items to consider for Renovation & Revamp projects ** ☐ Unforeseen issues related to the unique characteristics of renovation projects (i.e., hazardous materials, unknown underground structures or utilities, or other) ☐ Security clearance/ access control in operating areas during project execution ☐ Safety of occupants during emergency conditions related to renovation activities		The risk analysis and mitigation program and plan have been documented and approved, including unforeseen issues related to R&R projects, security clearance requirements, and the safety of occupants during emergency conditions.	Most of the R&R items related to the risk analysis and mitigation program and plan have been documented and are being reviewed.	Some of the R&R items related to risk analysis and mitigation have been identified, including assessing unforeseen issues related to the unique nature of R&R project, security clearance requirements, and the safety of occupants during emergency conditions.	Little or no meeting time or development hours have been expended on R&R items related to the risk analysis and mitigation program and plan.	

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
P. PROJECT EXECUTION PLAN	**0**	**1**	**2**	**3**	**4**	**5**
P1. Owner Approval Requirements Owner approval requirements have been developed. This document clearly defines all documents that require owner approval such as: ☐ Milestones for drawing approval: ☐ Comment ☐ Approval ☐ Bid issued ☐ Construction ☐ Electronic model reviews ☐ Durations of approval cycle compatible with schedule ☐ Individual(s) responsible for reconciling comments before return ☐ Types of drawings that require formal approval ☐ Purchase documents: ☐ Data sheets ☐ Inquiries ☐ Bid tabs ☐ Purchase Orders ☐ Change management approval authority ☐ Vendor information ☐ Other *Comments on Issues:* *The owner approval requirements plan is typically included into the project execution plan and contains submittal and return procedures, communications procedures, review and approval timing, main points of contact and steps to ensure timely review and approval with penalties for late reviews. Contractual documents that require owner approval typically include agreements, addendums to agreements, change orders and purchase orders. Engineering documents that require owner approval typically include drawings (e.g., process flow diagrams, piping and instrumentation diagrams, shared data models, 3D CADD models, hazards analysis reports), data sheets, design basis documents, manuals, philosophy documents and environmental reports. A matrix listing all documents that require approval and the individual responsible for approving the documents is typically prepared and agreed upon by all parties.*	**Not required for project.**	**The owner approval requirements plan has been documented and approved by key stakeholders (e.g., the business unit, engineering, project management).** The plan defines the documents that require owner approval including drawings, specifications, bid packages, purchase orders, and change orders. The plan defines interfaces and responsibilities between stakeholders/owners and engineering contractors. The resources required to support the plan have been identified.	**Most of the owner approval requirements plan has been documented and is under review, but not fully approved.** The owner approval requirements plan has minor issues that require resolution such as the final list of documents that require approval or approval requirements regarding model reviews or others. Some responsibilities and interfaces between stakeholders/owners and engineering contractors are still missing.	**Some of the owner approval requirements plan has been developed with open items.** The owner approval requirements plan has several issues that require resolution. These may include approval of documents critical to project execution process, definition and documentation of specific documents related to purchase orders, milestone requirements for engineering and construction drawings or other critical approval requirements. Interfaces and responsibilities between stakeholders/owners and engineering contractors are yet to be developed.	**Some of the owner approval requirements have been identified but nothing has been documented.** Initial thoughts have been applied to identifying the owner approval requirements; however, nothing has been documented. Little or no meeting time or development hours have been expended on this element.	**Not yet started.**

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SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
P. PROJECT EXECUTION PLAN	**0**	**1**	**2**	**3**	**4**	**5**
P2. Engineering/Construction Plan and Approach This documented plan identifying the methodology to be used in engineering and constructing the project should include items such as: ☐ Responsibility matrix ☐ Selected methods (e.g., design/build, CM at risk, competitive sealed proposal, bridging, design-bid-build, CM as agent, parallel prime contractors) ☐ Contracting strategies (e.g., lump sum, cost-plus) ☐ Subcontracting strategy ☐ Work week plan/schedule ☐ Organizational structure ☐ Work Breakdown Structure (WBS) ☐ Construction sequencing of events ☐ Safety requirements/program ☐ Environmental program ☐ Security requirements/program (e.g., access to site, inspection, background checks) ☐ Identification of critical lifts and their potential impact on operating units ☐ Quality assurance (QA)/quality control (QC) plan ☐ Information and communication technology infrastructure to support field operations, including licensing requirements ☐ Other *Comments on Issues:* *A critical output of the engineering/construction plan and approach is to have an effective cost estimate (for example, one that supports a +/- 10% cost estimate, or an AACEi Class 3 cost estimate) and schedule that include design, construction/demolition, professional service, contingency, startup and commissioning and so forth. Effective front end engineering design informs good cost estimates.*	**Not required for project.**	**The engineering and construction plan and approach has been documented and approved by key stakeholders (e.g., the business unit, operations and maintenance, engineering, project management, and construction groups).** The plan clearly defines the methodology for executing the engineering and construction on the project including a responsibility matrix. The plan includes the following sub-plans: engineering/design management, work package sequencing, safety, environmental, contracting, quality assurance (QA)/quality control (QC), communications, project controls, subcontracting, purchasing and commissioning and start-up plan, and a +/- 10 percent cost estimate developed according to the organization's procedures and practices.	**Most of the engineering and construction plan and approach has been documented and is under review, but not fully approved.** Most of the important aspects to develop engineering, procurement and construction activities are documented and planned in accordance with working packages following the right sequencing. The engineering and construction plan has minor issues that require resolution. The +/- 10 percent cost estimate is mostly complete. These may include further defining the commissioning/start -up and training plans or other minor issues with any of the other plans or methods employed on the project.	**Some of the engineering and construction plan and approach has been developed with open items.** The engineering and construction plan has several issues that require resolution. These may include further defining and documenting the construction sequencing plan, the safety requirements program, the quality assurance plan, the responsibility matrix or the identification of critical lifts and their impact on operating units. The +/- 10 percent cost estimate has a number of gaps.	**Some items of the engineering and construction plan and approach have been identified.** Initial thoughts have been applied to identifying the engineering and construction plan; however, there are numerous items that have not been identified and little has been developed. Little or no meeting time or development hours have been expended on this element and nothing has been documented. The +/- 10 percent cost estimate has a number of significant gaps.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
P. PROJECT EXECUTION PLAN	**0**	**1**	**2**	**3**	**4**	**5**
P2. Engineering/Construction Plan and Approach (Continue) ** Additional items to consider for Renovation & Revamp projects ** □ Flexible contracting arrangements for renovation projects such as a combination of unit price, cost reimbursable and lump sum □ Contingency for unforeseen conditions □ Specialized contractors for R&R activities, such as hazardous abatement or heavy haulers □ Responsibility for critical maintenance activities in the existing facility (i.e., routine maintenance during construction) □ Permits and approvals when working in or near continuing operations (i.e., hot work permitting, confined space, lift plans, environmental remediation, etc.) Coordination between multiple contractors and/or maintenance activities	**Not required for project.**	The engineering and construction plan and approach has been documented and approved, including flexible contracting arrangements for R&R projects, contingencies, specialized contractors, responsibility for critical maintenance activities, permits and approvals, and coordination between multiple contractors.	Most of the R&R items related to the engineering and construction plan and approach have been documented and are under review.	Some of the R&R items related to the engineering and construction plan and approach have been developed, including flexible contracting arrangements, contingencies, specialized contractors, responsibility for critical maintenance activities, permits and approvals, and coordination between multiple contractors.	Little or no meeting time or development hours have been expended on R&R items related to the engineering/construction plan and approach.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
P. PROJECT EXECUTION PLAN	**0**	**1**	**2**	**3**	**4**	**5**
P3. Shut Down/Turn-Around Requirements Required shut downs or turn-arounds have been identified and documented. Special effort should be made to contact the Shutdown/Turnaround Manager for ‘customer’ requirements relative to the unique issues surrounding a Shutdown / Turnaround. Typical issues to consider include but not limited to: □ Definitions of the scope of work to be accomplished during such down times □ Scheduled instructions for the down time □ Timing of outages □ Interface with other ongoing projects and operations □ Work force scale up and training and staff movement logistics □ Work protection considerations for the shutdown/turn-around □ Accuracy of information regarding the facility is known □ Standard reporting for progressing, forecasting, and frequency required by the Turnaround Manager. □ Identification of who approves emergent work-scopes during Turnaround and any ‘hurdle’ criteria it must meet to be approved. □ Identification of unique risks as a result of multiple projects working concurrently □ Identification of any “must do” requirements leading up to the Shutdown/Turnaround. □ Required emergency purchase/rental plans for materials, subcontractors, equipment, facilities, etc. □ Standard software required for integrating the master schedules e.g. Primavera □ The “triage” process for establishing priorities when resources are not available or there is a conflict/interference in space, equipment, etc. □ Manage conflicting contractual arrangements which may inhibit timely completion □ A functional accountability matrix has been established that will enable communication across multiple projects □ Safety □ Other	**Not required for project.**	**The shutdown/turnaround requirements have been documented and approved by key stakeholders (e.g., the business unit, operations and maintenance, project management).** The shutdown/turnaround plan should ensure that the key stakeholders are involved in the definition of work to be performed before, during, and after the outage. The approved plan defines how the shutdown/ turnaround requirements are executed. It covers the scope of working before, during and after the shutdown/ turnaround, resource loaded schedule, timing of outages, division of responsibilities, organization plan for interfacing with ongoing projects, contracting plan for workforce scaling, project controls plan for monitoring cost and schedule during the shutdown/turnaround, materials management/ logistics plan, a process safety management and safety plan. All participating parties have committed to the shutdown/ turnaround plan in terms of resource assignment and schedule adherence. A budget and schedule have been developed to address shutdown/turnaround requirements to support estimation of required work packages and deliverables.	**Most of the shutdown/turnaround requirements have been documented and are under review, but not fully approved.** The shutdown/turnaround requirements have minor issues that require resolution such as final schedules during the shutdown/turnaround . However, the engineering scope of work, and control documents clearly define the work to be performed pre-turnaround, during the turnaround, and post- turnaround. Instructions for drawings packages to be clearly labeled by phase have been defined and agreed upon.	**Some of the shutdown/ turnaround requirements have been developed with open items.** The shutdown/ turnaround requirements have several issues that require resolution. These may include specifically how the shutdown/turnaround activities will be executed, complete definition of the scope of work during the shutdown/turnaround , shutdown/turnaround team is not clearly defined, sequence of activities is not completely developed, or a definitive project controls plan.	**Some of the shutdown/ turnaround requirements have been identified.** Initial thoughts have been applied to identifying the shutdown/turnaround requirements; however, there are numerous requirements that have not been identified, including shutdown/ turnaround manager, and nothing has been developed. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
P. PROJECT EXECUTION PLAN	**0**	**1**	**2**	**3**	**4**	**5**
P4. Pre-Commissioning Turnover Sequence Requirements The owner's required sequence for turnover of the project for pre-commissioning and startup activation has been developed. It should include items such as: - Sequence of turnover, including system identification and priority - Contractor's and owner's required level of involvement in: - Pre-commissioning - Training - Testing - Clear definition of mechanical/electrical acceptance/approval requirements - Other *Comments on Issues:* *Construction knowledge and input is typically taken into account when considering the completeness of this element.*	**Not required for project.**	**Pre-commissioning requirements are documented and approved by key stakeholders as a basis for detailed design.** Definition of acceptance and approval criteria for mechanical and electrical systems have been issued, documented and approved. Items include: Systems identified on piping and instrumentation diagrams (P&ID's), testing requirements for mechanical equipment defined, systems identified on instrumentation and electrical (I&E) load list, systems identified on the input / output (I/O) list, the test package is identified on the piping line list, sequence of testing and turnover requirements is defined. The pre-commissioning plan includes: requirements for division of responsibility for pre-commissioning and training and testing, pre-commissioning / turnover schedule, testing and cleaning, dry out, oil flush, training, lubrication, equipment calibration, loop checks, motor run-ins, continuity checks, functional tests, turnover deliverables, pre-commissioning / turnover schedule, substation / switchgear /motor control centers (MCC's) testing, Meggar tests, transformer testing, instrument setting, calibration and adjustment. The lock out-tag out plan has been finalized and approved.	**Most pre-commissioning requirements are documented and under review, but not yet approved.** Most of the pre-commissioning requirements have been documented, but not yet approved. These items include: Definition of acceptance and approval criteria for mechanical and electrical systems, system definitions issued and systems identification included on P&ID's, testing requirements for mechanical equipment defined, the systems identification including I/O load list, test package identification on the piping line list or the sequence of testing and turnover may not have been developed. The pre-commissioning plan is documented but not yet finalized and includes requirements for division of responsibility for pre-commissioning, training and testing, pre-commissioning / turnover schedule, testing and cleaning, dry out, oil flush, training, lubrication, equipment calibration, loop checks, motor run-ins, continuity checks, functional tests, turnover deliverables, pre-commissioning / turnover schedule, substation / switchgear /motor control centers (MCC's) testing, Meggar tests, transformer testing, instrument setting, calibration and adjustment. The lock out-tag out plan may not have been finalized.	**Some of the pre-commissioning requirements are developed with holds for deficiencies.** Some of the pre-commissioning requirements have been documented. They include: The definition of acceptance and approval criteria for mechanical and electrical systems, systems definitions are issued, systems identifications are generally not included on the P&ID's, and the testing requirements for mechanical equipment may not be defined. The pre-commissioning plan is in progress but not yet finalized and includes some of the requirements for the division of responsibility for pre-commissioning, training and testing, pre-commissioning / turnover schedule, testing and cleaning, dry out, oil flush, training, lubrication, equipment calibration, and loop checks. The motor run-in, continuity checks, functional tests, turnover deliverables, and pre-commissioning / turnover schedule has generally not been finalized.	**Pre-commissioning requirements work has started.** The definition of acceptance and approval criteria for mechanical and electrical has started. Little to no other work has been done. The division of responsibility for pre-commissioning, training and testing is identified.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
P. PROJECT EXECUTION PLAN	**0**	**1**	**2**	**3**	**4**	**5**
P5. Startup Requirements Startup requirements have been defined and responsibility established. A process is in place to ensure that startup planning will be performed. Issues include: ☐ Startup goals ☐ Leadership responsibility ☐ Sequencing of startup ☐ Technology start-up support on-site, including information technology ☐ Feedstock/raw materials ☐ Off-grade waste disposal ☐ Quality assurance/quality control ☐ Work force requirements *Comments on Issues:* *Closeout requirements documents are an important component of startup requirements.*	**Not required for project.**	**Startup requirements are documented and approved by key stakeholders as a basis for detailed design.** The startup requirements have been defined and include startup goals and acceptance criteria, detailed process description, handling of feedstock / raw materials and products, system definitions, startup acceptance criteria, performance acceptance criteria, operations and maintenance (O&M) manual requirements, testing requirements, required startup spares, required consumables, and emissions testing criteria. The startup plan includes the division of responsibility, training and testing, start-up requirements / goals, technology startup support requirements, vendor support requirements, organizational responsibilities, cleaning and passivation, catalyst loading, off-site waste disposal, startup sequence / startup schedule, startup deliverables, functional testing criteria, startup acceptance criteria, software checkout, operator training plan, and troubleshooting checklist.	**Most startup requirements are documented and are under review, but not yet approved.** Most startup requirements have been defined, but not yet approved, and include startup goals and acceptance criteria, detailed process description, handling of feedstock / raw materials and products, system definitions, startup acceptance criteria, performance acceptance criteria, O&M manual requirements, testing requirements. Required startup spares, consumables and emissions testing criteria may not be developed. Most of the startup plan has been developed, but not yet approved, and includes the division of responsibility, training and testing, start-up requirements / goals, technology startup support requirements, vendor support requirements, organizational responsibilities, cleaning and passivation, catalyst loading, off-site waste disposal, startup sequence / startup schedule, startup deliverables, functional testing criteria, startup acceptance criteria. Software checkout, operator training plan and troubleshooting checklist are not finalized.	**Some startup requirements have been identified.** Some startup requirements have been defined, and include startup goals and acceptance criteria, detailed process description, handling of feedstock / raw materials and products, system definitions, startup acceptance criteria, performance acceptance criteria, O&M manual requirements, testing requirements. Some of the startup plan has been developed, and includes the division of responsibility, training and testing, start-up requirements / goals, technology startup support requirements, vendor support requirements, organizational responsibilities, cleaning and passivation, catalyst loading, off-site waste disposal. The startup sequence / startup schedule, the startup deliverables, functional testing criteria, and startup acceptance criteria are not finalized.	**Startup requirements work has started.** The definition of startup goals, acceptance criteria, and detailed process description, has started. No other startup engineering deliverables have been developed. The division of responsibility for start-up, training and testing, start-up requirements / goals, technology startup support requirements, vendor support definition, and organization plan, is being identified.	**Not yet started.**

SECTION III – EXECUTION APPROACH	Definition Level					
	N/A	BEST		MEDIUM		WORST
P. PROJECT EXECUTION PLAN	**0**	**1**	**2**	**3**	**4**	**5**
P6. Training Requirements Training requirements have been defined and responsibility established. Training has been identified in areas such as: ☐ Control systems ☐ Information systems and technology ☐ Equipment operation ☐ Maintenance of systems ☐ Training materials and equipment (e.g., manuals, simulations) ☐ Safety ☐ Other	**Not required for project.**	**The training requirements plan has been documented and approved by key stakeholders (e.g., engineering, operations and maintenance).** The training requirements plan defines the activities that will lead to a fully trained workforce in the operation of the facility. This workforce includes process operators, instrument technicians and mechanics. The plan consists of the development of training program, training program participants (e.g., operators, mechanics, engineers, facilitators, etc.), training program topics (operating goals and objectives, review of operating procedures, safety procedures, etc.), timing and location of the training, and required training certifications. A budget and schedule have been developed to address training requirements.	**Most of the training requirements plan has been documented and is under review, but not fully approved.** The training requirements plan has minor issues that require resolution such as the identification of the final list of participants, training facilities, or minor issues regarding training program topics.	**Some of the training requirements plan has been developed with open items.** The training requirements plan has several issues that require resolution. These may include complete definition of the training program, specific training program goals, location of training, list of participants, materials and equipment, safety training requirements or other critical issues related to the successful implementation of the training program.	**Some of the training requirements have been identified.** Initial thoughts have been applied to identifying training requirements, however; there are numerous requirements that have not been identified and nothing has been developed. Little or no meeting time or development hours have been expended on this element and nothing has been documented.	**Not yet started.**

APPENDIX C

PDRI ACCURACY SCORESHEETS

This appendix presents the accuracy scoresheets. There are four types of accuracy factors. The research results showed that each of these factors is important. Under each type, the factors are organized in order of importance from high to low.

Unweighted Accuracy Scoresheet

1. Project Leadership Team

The project leadership team is comprised of individuals each representing the interests of their respective stakeholders (e.g., owner, engineer, contractor, etc.) and are adept in the relevant subject matter in order to contribute to the decision making process that leads to favorable project outcomes.

Factors for Review	*High Performing*	*Meets Most*	*Meets Some*	*Needs Improvement*	*Not Acceptable*	***Row Score***
1a. Leadership team's previous **experience planning, designing and executing** a project of similar size, scope, and/or location, including FEP						
1b. **Stakeholders** are appropriately represented on the project leadership team						
1c. Project **leadership** is defined, effective, and accountable						
1d. **Leadership team and organizational culture** fosters trust, honesty, and shared values						
1e. Project leadership team's attitude is **able to adequately manage change**						
1f. **Key personnel turnover**, e.g., how long key personnel stay with the leadership team						
	Project Leadership Team Total Score					

2. Project Execution Team

The project execution team is the group of individuals responsible for executing the project. This group may be comprised of several project team members including the project manager, team leads, key stakeholders, vendors, and/or customer representatives.

Factors for Review	*High Performing*	*Meets Most*	*Meets Some*	*Needs Improvement*	*Not Acceptable*	***Row Score***
2a. **Technical capability and relevant training/certification** of the execution team						
2b. **Contractor/Engineer's team experience** with the location, with similar projects, and with the FEP process						
2c. **Stakeholders** are appropriately represented on the project team (e.g., contractor, operations and maintenance, key design leads, project manager, sponsor) and have a clear understanding of the project scope						
2d. Level of **involvement** of design leads or managers in the engineering process						
2e. Key personnel **turnover** including the **stability/commitment** of key personnel on the owner side through the FEP process						
2f. **Co-location** of execution team members						
2g. Team culture or history of the execution team **working together**						
	Project Execution Team Total Score					

3. Project Management Process

The project management process is the availability and application of standardized tools and methods to adequately implement clear requirements for the FEP process.

Factors for Review		*High Performing*	*Meets Most*	*Meets Some*	*Needs Improvement*	*Not Acceptable*	***Row Score***
3a.	**Communication** within the team is open and effective; a communication plan with stakeholders is identified						
3b.	Organization implements and follows a **front end planning** process (e.g., phase gates, clear requirements), has a **formal structure** or process to prepare FEP, and implements **planning tools** (e.g., checklists, simulations, and work flow diagrams) that are used effectively.						
3c.	**Priority** between cost, schedule, and required project features is clear						
3d.	Significant **input of construction knowledge** into the FEP process						
3e.	Adequate process for **coordination** between key disciplines						
3f.	**Alignment** of FEP process with **available project information,** including the existence of peer reviews and a standard procedure for updating FEP						
3g.	**Documentation** of information used in preparing FEP						
3h.	**Review and acceptance** of FEP by appropriate parties						
						Project Management Process Total Score	

4. Project Resources

Project resources are defined as the availability of key resources to support the FEP process, such as personnel, time, access, funding, technology/software availability, etc.

Factors for Review	*High Performing*	*Meets Most*	*Meets Some*	*Needs Improvement*	*Not Acceptable*	***Row Score***
4a. **Commitment** of key personnel on the project team 4b. **Calendar time** allowed for preparing FEP **Management tools** available including technology/software 4c. **Local knowledge** (e.g., institutional memory, understanding of laws and regulations, understanding of site history) and **access** to visit and **evaluate** the site 4d. **Quality** and level of detailed of engineering data available 4e. **Amount of funding** allocated to perform FEP 4f. **Availability of standards and procedures** (e.g., design standards, standard operating procedures, and guidelines)						
	Project Resources Total Score					

Weighted Accuracy Score Sheet

The following tables are the same as the previous accuracy score sheets; however, these tables contain the weights for each accuracy factor.

1. Project Leadership Team

The project leadership team is comprised of individuals each representing the interests of their respective stakeholders (e.g., owner, engineer, contractor, etc.) and are adept in the relevant subject matter in order to contribute to the decision-making process that leads to favorable project outcomes.

Factors for Review	*High Performing*	*Meets Most*	*Meets Some*	*Needs Improvement*	*Not Acceptable*	***Row Score***
1a. Leadership team's previous **experience planning, designing and executing** a project of similar size, scope, and/or location, including FEP	6	5	3	2	0	
1b. **Stakeholders** are appropriately represented on the project leadership team	6	5	3	2	0	
1c. Project **leadership** is defined, effective, and accountable	5	4	3	1	0	
1d. **Leadership team and organizational culture** fosters trust, honesty, and shared values	5	3	2	1	0	
1e. Project leadership team's attitude is **able to adequately manage change**	2	1	1	0	0	
1f. **Key personnel turnover**, e.g., how long key personnel stay with the leadership team	1	1	1	0	0	
Project Leadership Team Maximum Score = 25	**Project Leadership Team Total Score**					

2. Project Execution Team

The project execution team is the group of individuals responsible for executing the project. This group may be comprised of several project team members including the project manager, team leads, key stakeholders, vendors, and/or customer representatives.

Factors for Review	*High Performing*	*Meets Most*	*Meets Some*	*Needs Improvement*	*Not Acceptable*	***Row Score***
2a. **Technical capability and relevant training/certification** of the execution team	7	5	3	2	0	
2b. **Contractor/Engineer's team experience** with the location, with similar projects, and with the FEP process	6	5	3	2	0	
2c. **Stakeholders** are appropriately represented on the project team (e.g., contractor, operations and maintenance, key design leads, project manager, sponsor) and have a clear understanding of the project scope	5	4	3	1	0	
2d. Level of **involvement** of design leads or managers in the engineering process	3	2	2	1	0	
2e. Key personnel **turnover** including the **stability/commitment** of key personnel on the owner side through the FEP process	3	2	1	1	0	
2f. **Co-location** of execution team members	2	1	1	0	0	
2g. Team culture or history of the execution team **working together**	1	1	1	0	0	
Project Execution Team Maximum Score = 27					**Project Execution Team Total Score**	

3. Project Management Process

The project management process is the availability and application of standardized tools and methods to adequately implement clear requirements for the FEP process.

Factors for Review	*High Performing*	*Meets Most*	*Meets Some*	*Needs Improvement*	*Not Acceptable*	***Row Score***
3a. **Communication** within the team is open and effective; a communication plan with stakeholders is identified	5	3	2	1	0	
3b. Organization implements and follows a **front end planning** process (e.g., phase gates, clear requirements), has a **formal structure** or process to prepare FEP, and implements **planning tools** (e.g., checklists, simulations, and work flow diagrams) that are used effectively.	4	3	2	1	0	
3c. **Priority** between cost, schedule, and required project features is clear	4	3	2	1	0	
3d. Significant **input of construction knowledge** into the FEP process	2	2	1	1	0	
3e. Adequate process for **coordination** between key disciplines	2	2	1	1	0	
3f. **Alignment** of FEP process with **available project information,** including the existence of peer reviews and a standard procedure for updating FEP	2	1	1	0	0	
3g. **Documentation** of information used in preparing FEP	1	1	1	0	0	
3h. **Review and acceptance** of FEP by appropriate parties	1	1	0	0	0	
Project Management Process Maximum Score = 21	**Project Management Process Total Score**					

4. Project Resources *Project resources are defined as the availability of key resources to support the FEP process, such as personnel, time, access, funding, technology/software availability, etc.*						
Factors for Review	*High Performing*	*Meets Most*	*Meets Some*	*Needs Improvement*	*Not Acceptable*	***Row Score***
4a. **Commitment** of key personnel on the project team	6	4	3	1	0	
4b. **Calendar time** allowed for preparing FEP and **management tools** available including technology/software	5	4	2	1	0	
4c. **Local knowledge** (e.g., institutional memory, understanding of laws and regulations, understanding of site history) and **access** to visit and **evaluate** the site	4	3	2	1	0	
4d. **Quality** and level of detailed of engineering data available	4	3	2	1	0	
4e. **Amount of funding** allocated to perform FEP	4	3	2	1	0	
4f. **Availability of standards and procedures** (e.g., design standards, standard operating procedures, and guidelines)	4	3	2	1	0	
Project Resources Maximum Score = 27	**Project Resources Total Score**					

ACCURACY TOTAL SCORE

(Maximum Score = 100)

This score represents the accuracy index between 0 and 100, with 100 having the highest possible accuracy.

APPENDIX D

PDRI ACCURACY FACTOR DESCRIPTIONS

This appendix showcases the accuracy factor descriptions for the four accuracy types. Refer to this appendix when completing the accuracy assessment during front end planning.

1. PROJECT LEADERSHIP TEAM

The project leadership team is comprised of individuals each representing the interests of their respective stakeholders (e.g., owner, engineer, contractor, etc.) and are adept in the relevant subject matter in order to contribute to the decision making process that leads to favorable project outcomes.

Factor	Project Leadership Team Accuracy Factors	Description
1a.	Leadership team's previous **experience planning, designing and executing** a project of similar size, scope, and/or location, including FEP	Previous experience increases the familiarity of the leadership team with the project planning, design, and execution processes. Repetition plays a major role in both organizational learning (lessons learned) and in the creation of routines and capabilities in general.
1b.	**Stakeholders** are appropriately represented on the project leadership team (e.g., sponsor, marketing, project management, operations and maintenance) and have a clear understanding of the project scope	Proper stakeholder input provides the leadership team with diverse expertise that covers both the technical and management areas of the project. This diverse expertise facilitates better solutions and sound judgments to the problems faced by the team.

Factor	Project Leadership Team Accuracy Factors	Description
1c.	Project **leadership** is defined, effective, and accountable	Project leadership roles will vary across organizations and typically include a venture manager, project sponsor, project director, construction manager, operation manager and others. Additionally, organizational structure typically follows the hierarchy of executive steering committee, project leadership team and project execution team. Furthermore, the project sponsor and board of directors can affect the accuracy of a project. These individuals ultimately will be held accountable for project success. Moreover, components of good leadership typically include: • Good general knowledge of contracting strategy, project phases, and project delivery systems for the construction industry • Good understanding of related business critical success factors • Capacity to determine and align the needs of the key stakeholders • Adequate understanding of facilities operations and start-up • Good understanding of assessing and managing uncertainties and risks
1d.	**Leadership team and organizational culture** in the support of FEP fosters trust, honesty, and shared values	Culture is, by definition, the display of behaviors. Organizational culture is a system of common assumptions, values, and beliefs, which governs how people behave in organizations. Organizational values and beliefs displayed in the leadership team should align with the development and outcomes of a successful FEP.
1e.	Project leadership team's attitude is **able to adequately manage change**	The project leadership team's attitude is able to adequately manage change. The leadership team having processes to manage change; and whether change has (or has not) created a negative attitude, may affect the accuracy of FEP.

Factor	Project Leadership Team Accuracy Factors	Description
1f.	**Key personnel turnover**, e.g., how long key personnel stay with the leadership team	Personnel turnover is a measure of how long individuals stay with the leadership team and how often they are replaced. Excessive turnover will lead to loss of knowledge and perspective. Stable and committed FEP teams will be more productive and generate more valuable outcomes because stability and commitment of the team will create an uninterrupted FEP process flow. For example, key personnel at different levels on the leadership team should show their commitment throughout the FEP process by always communicating its objectives and its required deliverables. A plan is in place to prevent turnover or mitigate when turnover is experienced.

2. PROJECT EXECUTION TEAM

The project execution team is the group of individuals responsible for executing the project. This group may be comprised of several project team members including the project manager, team leads, key stakeholders, vendors, and/or customer representatives.

Factor	Project Execution Team Accuracy Factors	Description
2a.	**Technical capability and relevant training/certification** of the execution team	The execution team has individuals with the necessary experience, technical background, and training in the relevant subject matter to provide professional input and contribute to decision making based on acceptable best practices and recognizable standards and methods. Training includes Project Definition Rating Index (PDRI) training, FEED training, and any other project-specific and/or technology-specific training. Also, project execution team members ideally have knowledge of local/regional regulations and permitting/design requirements.
2b.	**Contractor/Engineer's team experience** with the location, with similar projects, and with the FEP process	Previous experience increases the familiarity of the execution team with the project planning, design, and execution processes. Repetition plays a major role in both organizational learning (lessons learned) and in the creation of routines and capabilities in general.
2c.	**Stakeholders** are appropriately represented on the project execution team (e.g., contractor, operations and maintenance, key design leads, project manager, sponsor) and have a clear understanding of the project scope	Proper stakeholder input provides the execution team with diverse expertise that covers the technical and management areas of the project. This diverse expertise facilitates better solutions to the problems faced by the team. These, in turn, help improve team alignment by providing a sound foundation for a successful FEP. Stakeholders effectively communicate expectations to the project team, monitor progress, and assist with key decisions.
2d.	Level of **involvement** of design leads or managers in the engineering process	The involvement of design leads or managers helps develop and maintain a collaborative business environment in which an organization can achieve its strategic and mission goals. Lack of involvement by design leads or managers may lead to poor coordination and quality issues.

Factor	Project Execution Team Accuracy Factors	Description
2e.	Key personnel **turnover**, including the **stability/commitment** of key personnel on the owner side throughout the FEP process	Personnel turnover is a measure of how long individuals stay with the execution team and how often they are replaced. Excessive turnover will lead to loss of knowledge and perspective. Stable and committed FEP teams will be more productive and generate more valuable outcomes because stability and commitment of the team will create an uninterrupted FEP process flow. For example, key personnel at different levels on the owner side should show their commitment throughout the FEP process by always communicating its objectives and its required deliverables. A plan is in place to prevent turnover or mitigate when turnover is experienced.
2f.	**Co-location** of execution team members	Team members who are co-located tend to develop a shared purpose, goals, and culture. The co-location of team members also facilitates the development of a positive team climate, independent team processes, maturation of team members, and the team itself. Lack of co-location may lead to lack of alignment and effective communication. Additionally, co-location of team members may be affected by time-zones and language barriers.
2g.	Team culture or history of the execution team **working together**	Current or previous experiences of the execution team members working together on different projects increase the probability of more cohesiveness and familiarity with other team members' strengths and expertise. Familiarity will improve the ability of the execution team to act in a coordinated manner.

3. PROJECT MANAGEMENT PROCESS

The project management process is the availability and application of standardized tools and methods to adequately implement clear requirements for the FEP process.

Factor	Project Management Process Accuracy Factors	Description
3a.	**Communication** within the team is open and effective; a communication plan with stakeholders is identified	An open and effective communication channel exists at all times to transfer FEP information in an efficient and expedient manner. Communication is important for building and maintaining a productive interface between the FEP team and stakeholders.
3b.	Organization implements and follows a **front end planning** process (e.g., phase gates, clear requirements), has a **formal structure** or process to prepare FEP, and implements **planning tools** (e.g., checklists, simulations, and work flow diagrams) that are used effectively	CII defines front end planning (FEP) as "the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project." The FEP process is followed and includes a phase gate process; phase gates describe clear completion requirements. These requirements include a formal structure or process to prepare FEP, which is agreed upon by the stakeholders and is easy to implement. The formal FEP structure ensures work can be completed in a consistent manner, and results can be measured and compared. Additionally, planning tools are used to produce fundamental decisions and actions that shape and guide the FEP process.
3c.	**Priority** between cost, schedule, and required project features is clear	Setting priorities enables the project team to determine which project aspect is most essential (e.g., cost, schedule, required features). These priorities support scope definition, decision-making, risk management, plan optimization, negotiating project changes, and integrated change control.
3d.	Significant **input of construction knowledge** into the FEP process	Constructability (or buildability) is a project management technique to review construction processes from start to finish during the pre-construction phase. In the case of FEP, with the significant input of construction knowledge, obstacles that typically hinder the construction process are identified well in advance to reduce or prevent errors, delays and cost overruns.

Factor	Project Management Process Accuracy Factors	Description
3e.	Adequate process for **coordination** between key disciplines	A formal structure of interaction between the key disciplines involved in preparing FEP enables them to coordinate effectively. Specifically, a cross-trade coordination and collaboration plan exists to assist discipline leads, compliance reporting, audits, etc.
3f.	**Alignment** of FEP process with **available project information**, including the existence of peer reviews and a standard procedure for updating FEP	The state of alignment between the FEP process and the available project information is confirmed using peer reviews, which serve as a first inspection point for the validity and quality of the work. Moreover, there are formal or prescribed methods to be followed routinely for updating FEP.
3g.	**Documentation** of information used in preparing FEP	A records management plan exists, providing a process of classifying and recording FEP information in a consistent and clear manner. Good documentation is crucial for a successful FEP.
3h.	**Review and acceptance** of FEP by appropriate parties	A formal and timely assessment or examination of FEP with the possibility of instituting changes, if necessary. If the FEP review and acceptance criteria are clear, then the appropriate parties only have to check the FEP deliverables against the requirements. These requirements are established at the beginning of the FEP process, where the objectives are understood.

4. PROJECT RESOURCES

Project resources are defined as the availability of key resources to support the FEP process, such as personnel, time, access, funding, technology/software availability, etc.

Factor	Project Resources Accuracy Factors	Description
4a.	**Commitment** of key personnel on the project team	The availability and protected time of key team individuals who contribute to the preparation of FEP in a substantive and measurable way. Typically this also includes the availability/commitment of consultants with specialized skills/knowledge, who may or may not be "dedicated" to the project.
4b.	**Calendar time** allowed for preparing FEP	The total number of allocated working days to prepare FEP, which is sufficient to allow reasonable effort and products rather than unrealistic expectations.
4c.	**Local knowledge** (e.g., institutional memory, understanding of laws and regulations, understanding of site history) and **access** to visit and **evaluate** the site	The knowledge that the project team and subject matter experts have developed over time in a given area ensures that the FEP is based on experience and adapted to the local culture and environment. For international projects, the project team should consider government influence, international codes and standards, taxes, foreign exchange rates, and applicable labor laws. Additionally, access to the project site provides the project team with hands-on review and allows field verification of the site characteristics. This factor is extremely important for projects involving renovation and revamp construction activities.
4d.	**Quality** and level of detail of engineering data available (e.g., as-builts, geotechnical, renovation history, site information).	FEP outputs are only as good as the engineering and project management data used. FEP data are generally considered high quality if they are detailed, timely, and adequate for their intended uses in planning, decision making and operations.
4e.	**Amount of funding** allocated to perform the FEP	Sufficient funds to support the FEP process from initiation until the final FEP deliverables are documented and approved.

Factor	Project Resources Accuracy Factors	Description
4f.	**Availability and understanding of standards and procedures** (e.g., design standards, standard operating procedures, and guidelines)	Availability, knowledge, and experience with applicable codes; clarification documents; and organizational, international, and national standard methodologies that specify characteristics and technical details that must be met by the project, systems and processes that FEP covers.

APPENDIX E

EVMS MATURITY AND ENVIRONMENT SURVEY QUESTIONS

Assessing the Maturity and Environment of Earned Value Management Systems (EVMS)

Overview The purpose of this study is to focus on assessing the maturity and accuracy of Earned Value Management Systems (EVMS) to support project progress management for both government agencies and contractors. The team is working to develop a more objective, scalable, effective and efficient framework to evaluate EVMS quality when applied to diverse projects.

Confidentiality statement:

All data provided to Arizona State University (ASU) in support of this research activity will be considered confidential information. Individual company data will not be communicated in any form to any party other than the ASU authorized academic researchers. Any data or analyses based on these data that are shared with others or published will represent summaries of data from multiple participating organizations that have been aggregated in a way that will preclude identification of proprietary data. If you have any questions about the survey, please contact Dr. G. Edward Gibson, Jr. (egibson4@asu.edu) or Dr. Mounir El Asmar (asmar@asu.edu). For your information, the participant consent form can be found here. Please provide your contact information if you wish to be part of any follow-ups. Please note that when you answer questions, you must also click on the **NEXT** button to move to the following screen.

○ Name: ______________________________

○ Organization: ______________________________

○ Phone: ______________________________

○ E-mail: ______________________________

Q1 Please indicate your Employer.

- ○ Government
- ○ Manufacturer/constructor
- ○ Consultant
- ○ Software developer
- ○ Government contractor
- ○ Other: ____

Q2 Please provide your typical employment role.

- ◯ Project management
- ◯ Finance
- ◯ Scheduling
- ◯ Engineering
- ◯ Systems engineering
- ◯ Control accounts management (CAM)
- ◯ Project controls management
- ◯ Consulting
- ◯ Compliance management
- ◯ Executive or senior management
- ◯ Other: ____

Q3 How many years of work experience do you have in total?

○ < 5 years

○ 5 to 10

○ 11 to 15

○ 16 to 20

○ 21 to 25

○ > 25 years

Note The following questions will focus on *Earned Value Management (EVM)* as a concept. Later questions will focus on *Earned Value Management Systems (EVMS)*.

Q4 Does your organization have a standardized definition of *Earned Value Management (EVM)*?

○ Yes

○ No

Q5 Please provide your organization's definition of *Earned Value Management* (*EVM)* below:

____

____

____

____

____

Q6 Below is our research team's working <u>definition</u> of *Earned Value Management (EVM)*:

"*EVM* is the use of performance management information produced from the *EVM system*, to plan, direct, and control the execution and accomplishment of contract/project cost, schedule, and technical performance objectives." Do you agree with this *EVM* definition?

○ Yes

○ No

Q7 Below is our research team's working <u>definition</u> of *Earned Value Management (EVM)*:

"*EVM* is the use of performance management information produced from the *EVM system*, to plan, direct, and control the execution and accomplishment of contract/project cost, schedule, and technical performance objectives."
Since you answered *No*, please provide comments below:

____

____

____

____

____

Q8 Does your organization have <u>another term</u> that is used in place of the term *Earned Value Management (EVM)*? (e.g., integrated program management)

◯ Yes

◯ No

Q9 Does your organization have <u>another term</u> that is used in place of the term *Earned Value Management (EVM)*?

Since you answered *Yes*, please provide your organization's other term that is used in place of the term *EVM* (e.g., integrated program management).

____

____

____

____

____

Note *The following questions focus on Earned Value Management Systems.*

Q10 Does your organization have a standardized <u>definition</u> of *Earned Value Management System (EVMS)*?

◯ Yes

◯ No

Q11 Does your organization have a standardized <u>definition</u> of *Earned Value Management System (EVMS)*?

You answered *Yes*; please provide your organization's definition of *EVMS* below:

____

____

____

____

____

Q12 Below is our research team's working <u>definition</u> of *Earned Value Management System (EVMS)*.

"*EVMS* is an organization's management system for project/program management that integrates a defined set of associated work scopes, schedules and budgets for effective planning, performance, and management control."

Do you agree with this *EVMS* definition?

○ Yes

○ No

Q13 Below is our research team's working <u>definition</u> of *Earned Value Management System (EVMS)*.

"*EVMS* is an organization's management system for project/program management that integrates a defined set of associated work scopes, schedules and budgets for effective planning, performance, and management control."

Since you answered *No*, please explain why you disagree by providing comments below:

____

____

____

Q14 Does your organization have <u>another term</u> that is used in place of the term *Earned Value Management System (EVMS)*? (e.g., integrated program management system)

- ◯ Yes
- ◯ No

Q15 Does your organization have <u>another term</u> that is used in place of the term *Earned Value Management System (EVMS)*?

Since you answered *Yes*, please provide your organization's other term that is used in place of the term *EVMS* (e.g., integrated program management system).

Q16 Does your organization evaluate maturity of *Earned Value Management System (EVMS)* <u>in addition</u> to *EVMS* compliance? For example, do you have a document that provides specific criteria for giving a 1, 2, 3, 4, or 5 score (on a Likert scale) for the NDIA EIA 748-D's 32 guidelines, or other similar assessment mechanisms?

"**<u>Note:</u>** Maturity does not only mean compliance. *EVMS Maturity* is defined as the degree to which an implemented system, associated processes, and deliverables serve as the basis for an effective and compliant *EVMS*."

○ Yes

○ No

Q17 Does your organization evaluate maturity of *Earned Value Management System (EVMS)* in addition to *EVMS* compliance? For example, do you have a document that provides specific criteria for giving a 1, 2, 3, 4, or 5 score (on a Likert scale) for the NDIA EIA 748-D's 32 guidelines, or other similar assessment mechanisms?

"**Note:** Maturity does not only mean compliance. *EVMS Maturity* is defined as the degree to which an implemented system, associated processes, and deliverables serve as the basis for an effective and compliant *EVMS*."

Since you answered that *EVMS maturity* is evaluated in your organization, **how** is maturity evaluated? **Check all that apply.**

- ☐ An internal organizational proprietary maturity model or framework
- ☐ Using a consulting organization's maturity model or framework
- ☐ Other ____

Q18 Does your organization evaluate maturity of *Earned Value Management System (EVMS)* in addition to *EVMS* compliance? For example, do you have a document that provides specific criteria for giving a 1, 2, 3, 4, or 5 score (on a Likert scale) for the NDIA EIA 748-D's 32 guidelines, or other similar assessment mechanisms?

"Note: Maturity does not only mean compliance. *EVMS Maturity* is defined as the degree to which an implemented system, associated processes, and deliverables serve as the basis for an effective and compliant *EVMS*."

Since you answered that *EVMS maturity* is evaluated in your organization, **who** typically conducts this evaluation? **Check all that apply.**

- ☐ The EVMS subject matter expert or organization's EVMS office
- ☐ By the contractor
- ☐ By the client/customer
- ☐ By the owner
- ☐ Third party peer review
- ☐ Consulting review
- ☐ Other: ________________________________
- ☐ Other: ________________________________

Q19 What are the most challenging aspects of managing a project/program using the *Earned Value Management System (EVMS)*. Please rank the **top three**, with one being the most challenging aspect. (#1 is the most challenging).

______ Complexity of implementation
______ Implementation costs
______ Local/resident experience
______ Leadership/manager attitudes towards EVMS
______ Providing timely data and information for decision making
______ Flexibility or scalability to different types of organizations and projects
______ Antiquated management practices, methodologies, and toolsets
______ Customer/government support of EVMS use
______ The extent of compliance expectations, reviews, and oversight
______ Other:
______ Other:

Q20 The following core processes typically make up an *Earned Value Management (EVM) system*. In your opinion, please rank the **top three** in the list below in terms of their impact on *EVMS* effectiveness. (#1 is the highest impact.)

______ Organizing Process
______ Planning and Scheduling Process
______ Budget & Authorization Process
______ Accounting Process
______ Indirect Costs Process
______ Management Analysis Process
______ Change Control Process
______ Subcontract Management Process
______ Material Management Process
______ Risk Management Process
______ Other:

Q21 The following factors can impact the environment of *Earned Value Management (EVM) systems*. Based on your experience, please rank the **top 5** factors in order of importance (#1 is the most important).

"*Earned Value Management System (EVMS) Environment* is the conditions (i.e., people, culture, practices, and resources) that enable or limit the ability to manage the project/program using the EVMS, serving as a basis for timely and effective decision-making."

______ Leadership team's previous **experience planning, designing and executing** an EVMS on a project/program of similar size, scope, and/or location
______ **EVMS Stakeholders** are appropriately represented on the project leadership team
______ Project/Program **leadership** is defined, effective, and accountable
______ **Organizational culture** fosters trust, honesty, and shared values
______ **Technical capability and relevant training/certification** of EVMS implementation team
______ **EVMS implementation team experience** with the local regulations, with similar projects
______ **Internal controls team** is independent of the program and has the authority to affect change
______ **Stakeholders** are appropriately represented on the EVMS implementation team (e.g., contractor, operations and maintenance, key design leads, project manager, sponsor) and have a clear understanding of the project scope
______ **Communication** within the EVMS implementation team is open and effective; a communication plan with stakeholders is identified
______ The organization implements and follows a standard EVMS Development process, has a **formal structure** or process to prepare EVMS, and implements **planning tools** that are used effectively
______ **Priorities** among EVMS requirements are clear
______ **Commitment** of key EVMS personnel
______ **Calendar time** allowed for preparing EVMS and **management tools** available including technology/software
______ **Local knowledge** (e.g., institutional memory, understanding of laws and regulations, understanding of site history)
______ **Quality** and level of data available
______ **Sufficient investment** to implement EVMS
______ **Availability of standards and procedures** (e.g., local EVMS requirements, standard operating procedures, and guidelines)
______ **Sufficient EVMS requirements definition and agreement** among key stakeholders and sponsor(s)
______ Other:
______ Other:

Q22 Please provide key strategies that your organization uses to identify and mitigate *Earned Value Management System (EVMS)* deficiencies or take advantage of opportunities for improvement.

____

____

____

Q23 Please feel free to share any other thoughts about *Earned Value Management System (EVMS)* assessment with the research team.

____

____

____

____

____

APPENDIX F

IRB EXEMPTION LETTER

EXEMPTION GRANTED

Mounir El Asmar
SEBE: Sustainable Engineering and the Built Environment, School of
480/727-9023
asmar@asu.edu

Dear Mounir El Asmar:

On 8/28/2019 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Improving the Reliability of Earned Value Management System (EVMS) Compliance Reviews and EVMS Maturity Level Assessments: Development of an EVMS Maturity Level Rating Index
Investigator:	Mounir El Asmar
IRB ID:	STUDY00010395
Funding:	Name: DOE: Headquarters
Grant Title:	
Grant ID:	
Documents Reviewed:	• Survey questionnaire, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Funded Grant GR35990, Category: Grant application; • Protocol, Category: IRB Protocol; • Consent, Category: Consent Form; • recruitment message, Category: Recruitment Materials;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 8/28/2019.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Bethany Skabelund
George Gibson
Namho Cho

APPENDIX G

EVMS LITERATURE REVIEW LIST

The following Appendix presents 294 references that selected from 395 references and used in maturity and environment analysis. Each symbol represents below EVMS processes and environment categories.

EVMS Processes

A. Organizing Process

B. Planning and Scheduling Process

C. Budgeting and Work Authorization Process

D. Accounting Considerations Process

E. Indirect Budget and Cost Management Process

F. Analysis and Management Reporting Process

G. Change Control Process

H. Material Management Process

I. Subcontract Management Process, and

J. Risk Management Process

EVMS Environment

1. Culture
2. People
3. Practices
4. Resources

Year	Title	Processes										Environment			
		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2016	Developing the Project Work Breakdown Structure	X													
2014	Level of Effort Planning and Execution on Earned Value Projects - Within the Framework of ANSI EIA-748		X												
2014	Required Skills and Knowledge of Earned Value Management												X		
2013	EVM Self-Surveillance Approach										X			X	X
2012	Accepted Standards and Emerging Trends in Over Target Baseline (OTB) Contracts		X					X							
2017	Case Study: Using ISO 20000 to Supplement Earned Value Management													X	
2013	Earned Value Management Guidelines: Accounting Considerations, Analysis and Management Reports, Revisions and Data Maintenance				X		X	X							
2013	Earned Value Management Guidelines: Organization and Planning, Scheduling and Budgeting	X	X												
2012	Designing a Tailored Earned Value Management System (EVMS)													X	X
2012	How the Department of Defense Determines If EVM Should Be Required and What Contractual Requirements Are Necessary If the Answer Is 'Yes.'													X	
2015	Data Driven EVMS Compliance: An Analytical Approach That Will Transform The Way We Think About Managing														X
2015	IPMR Tailoring: Data You Can Count On						X								X
2011	Cost of Earned Value Management														X
2011	Our EVM Professional Organization — An Evolving Process													X	
2017	Improving EVMS Compliance through Data Integration														X
2015	A Critical Analysis of the ANSI/EIA Standard for EVMS and the TCM Framework			X		X		X						X	
2006	EVMS Internal and DCAA Audit Recommendations													X	X
2012	The U.S. Government Accountability Office's New Schedule Assessment Guide		X											X	
2011	Ownership and Control of Management Reserve			X				X							
2011	Lawrence of Arabia and Non-Compliant Earned Value (EV)	X	X	X	X	X	X	X	X	X	X				
2015	Managing by Exception – Simplifying Earned Value for Mainstream Application	X	X	X	X	X	X	X	X	X	X				

Year	Title	Processes										Environment			
		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2014	Planning for EVM within Basic Project Controls Deliverables	X	X	X	X										
2015	A Survival Guide for Using EVMS on Small EPC Projects													X	X
2017	Adopting a Flexible EVM Strategy to Optimize Project Performance													X	
2016	EVMS Recommendations for Multi-Contract Projects	X												X	
2018	Structuring a Schedule and Cost System (Generic) for an Integrated Cost/Schedule EVMS	X	X	X	X										
2018	On the Psychology of Human Misjudgment: Charlie Munger on Decision-Making											X	X		
2019	(Panel Discussion) Project Controls in an OS 2.0 Environment													X	X
2013	Earned Value Management	X	X	X	X	X	X	X	X	X	X				
2019	Earned Value Challenges in Projects With Different Project and Functional Currencies				X										
2014	The Project Management Body of Knowledge: Comprehension and Practice	X	X	X	X	X	X	X	X	X	X				
2005	Earned Value Project Management	X	X	X	X	X	X	X	X	X	X				
2014	Earned value management system		X	X	X	X	X	X	X	X	X				
2017	Cutting the Cost of Earned Value Management														X
2013	Lessons Learned in Earned Value Management System Certification														X
2017	All Aboard! Earned Value Management in DoD														
2018	Demystifying Artificial Intelligence & How it Will Make Project Planning Better														
2015	Enhancing EVM: Providing the Best Value to all project stakeholders														
2017	PMI Lexicon of Project Management Terms														
2011	Small Projects, Big Savings by Implementing Best Practices with Earned Value Management (Lessons Learned)														X
2017	GAO Best Practice Guides Light the Way														
2018	Accounting for Software: Understanding CAPEX and OPEX				X										
2010	Earned Value Management: A Global and Cross-Industry Perspective on Current EVM Practice	X	X	X	X	X	X	X	X	X	X				

Year	Title	Processes										Environment			
		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2019	Program Management Lessons Learned: Alaskan Way Viaduct Replacement Program														X
2010	Project Baseline Management and Change Control		X				X	X							
2014	Forecasting project schedule performance using probabilistic and deterministic models					X	X								
2019	How to Calculate Estimate at Completion at a Project Level					X	X								
2014	Building A Credible Performance Measurement Baseline		X			X									
2018	Forecasting Project Completion Date Using Earned Schedule and Primavera P6TM					X	X								
2017	Improving project forecast accuracy by integrating earned value management with exponential smoothing and reference class forecasting					X	X								
2015	Evaluation of deterministic state-of-the-art forecasting approaches for project duration based on earned value management					X	X								
2014	Guidelines for Schedule Displays An Organized Approach to Improving Schedule Displays						X								
2019	The Power of Projections: Innovative Schedule Forecasting Techniques					X	X								
2012	The Total Float Consumption Index (TFCI)		X												
2016	Earned value project management: Improving the predictive power of planned value					X	X								
2013	A Comparison of Earned Value Management and Earned Schedule as Schedule Predictors on DoD ACAT I Programs		X				X								
2019	Emergent EVM Techniques for Construction Schedule Performance Measurement and Control					X	X	X							
2011	Earned Progress Management — A Unified Theory of Earned Value & Earned Schedule Concepts					X	X	X							
2013	Impact of Sensitivity Information on The Prediction of Project's Duration Using Earned Schedule Method					X	X								
2016	The Two Most Useful Earned Value Metrics: the CPI and the TCPI					X	X								
2013	Two Scheduling Models, One Project: Are Models Applicable in Case of Real Projects?		X												
2015	Forecasting DoD Mid-Acquisition Space Program EACs Using WBS Level 2 and 3 Data	X	X			X	X								

Year	Title	Processes										Environment			
		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2012	Contract Over Target Baseline (OTB) Effect on Earned Value Management's Cost Performance Index (CPI)		X			X	X	X							
2015	Using Budgeted Cost of Work Performed to Predict Estimates at Completion for Mid-Acquisition Space Programs					X	X								
2012	Time Prediction in Construction Projects with Earned Schedule Longest Path (ES-LP)		X				X								
2014	Earned Value Analysis and CPM Schedule Review In Construction		X												
2019	Earned Schedule Forecasting Method Selection		X			X	X								
2017	Forecasting Schedule Variance Using Earned Schedule					X	X								
2017	Assessing Earned Value Management and Earned Schedule Forecasting					X	X								
2015	Applying Statistical Forecasting of Project Duration To Earned Schedule-Longest Path		X			X	X								
2013	Earned Schedule – Ten Years After		X			X	X								
2012	Speculations on Project Duration Forecasting														
2012	Further Study of the Normality of CPI and SPI(t)					X	X								
2011	Why Should CPI = 1?					X	X								
2011	Earned Schedule Application to Small Projects														X
2011	Is Something Missing from Project Management?											X			
2016	The Probability of Project Recovery						X				X				
2016	Examination of the Threshold for the To Complete Indexes						X				X				
2016	The To Complete Performance Index... An Expanded View						X								
2011	Schedule Adherence and Rework					X	X								
2017	Trust, but Verify: An Improved Estimating Technique Using the Integrated Master Schedule (IMS)						X					X			
2018	How to Successfully Use Earned Value on Projects														X
2012	Customize your Independent Estimate at Completion (IEAC) Formula					X	X								
2014	An Earned Schedule-based regression model to improve cost estimate at completion					X	X								

Year	Title	Processes										Environment			
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**1**	**2**	**3**	**4**
2014	SPI(t) Stability: Analyzing DoD Contracts					X	X								
2014	The SMARTER Project - ‘A Best Value Performance Measurement System											X			
2011	Scheduling simulation-based techniques for earned value management on resource-constrained schedules under delayed scenarios						X				X				
2006	A comparison of different project duration forecasting methods using earned value metrics					X	X								
2017	Earned Duration Management for a Student Association Project					X	X								
2013	Project Management using Dynamic Scheduling: Baseline Scheduling, Risk Analysis & Project Control		X			X	X				X				
2012	Project Management with Dynamic Scheduling		X												
2013	Measuring Schedule Adherence		X			X	X								
2017	Understanding the use of TCPI in EVM					X	X								
2018	Increasing the Probability of Program Success with Continuous Risk Management							X			X				
2018	What is Risk?										X				
2016	Building Risk Tolerance into the Program Plan and Schedule						X				X				
2010	Technical Guide FAIR – ISO / IEC 27005 Cookbook										X				
2011	Treatment of Project Risk Management Strategies Relative to the Performance Measurement Baseline		X								X				
2006	Earned Value Based Forecasts - Some Pitfalls						X								
2015	Earned Value Analysis, The FAIR model										X				
2018	Cost Risk Management										X				
2013	Integrated Cost-Schedule Risk Analysis										X				
2013	Understanding CAM Requirements for Subcontract EV flow down and Management				X						X				
2011	How to Estimate and Use Management Reserve in an Earned Value Management System (EVMS)			X				X							
2019	Concurrently Verifying and Validating the Critical Path and Margin Allocation Using Probabilistic Analysis		X								X				

Year	Title	Processes										Environment			
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**1**	**2**	**3**	**4**
2013	PARCA: The Next Generation of Earned Value Management														X
2014	A Program Management Decision Process										X	X	X	X	
2012	Establishing and Defending Management Reserve for Acquisition Success			X				X			X				
2000	Total Project Cost Success Factors										X				
2013	10 Do's and Don'ts for Using Performance Management Data										X				
2013	Ensuring Quality in Project Planning, Forecasting, and Execution										X				X
2009	Practice Standard Project Risk Management										X				
2007	Performance-Based Earned Value						X				X				
2003	Operational Risk Management Training & Resources										X		X	X	
2018	An Engineering Approach to Schedule Risk Management										X				
2012	Dynamic Scheduling: Integrating Schedule Risk Analysis with Earned Value Management		X								X				
2017	Agile's Earned Schedule Baseline		X								X				
2015	Construction and evaluation framework for a real-life project database														X
2017	Joint Space Cost Council Better Earned Value Management System Implementation Research Study														X
2007	New Directions in Project Performance and Progress Evaluation						X								
2013	Applying Earned Value to Overcome Challenges in Oil and Gas Industry Surface Projects													X	X
2011	Earning Value the Agile Way: Using Story Points to Generate EV Metrics					X	X								
2014	Application of Earned Value Method to Progress Control of Construction Projects					X	X	X			X				
2013	Earned value-based performance monitoring of facility construction projects					X	X	X							
2015	Quality: The Third Element of Earned Value Management						X								
2018	Under-Spend: An Earned Value Analysis of 60 Projects in the Sahel														X
2012	Adapting EVM to Pressure Equipment Manufacturing														X
2017	The Power of Data: New Thinking and Technology Can Keep EVMS Relevant														X

Year	Title	Processes										Environment			
		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2012	‘Real Time’ Performance Reporting Using Earned Value for the Mining Sector						X								
2016	A Template for EPC Project Management and Execution													X	X
2014	White Paper: ‘The Three Aspects of EVMS Sustainability’						X								
2011	The Challenge for Earned Value in Commercial Industry											X	X	X	X
2017	Intelligently Linking Information for Better Performance Management Across Industry and Government											X		X	X
2000	Project Performance Control in Reconstruction Projects						X								
2013	Technical Performance Based Earned Value as a Management Tool for Engineering Projects						X								
2011	Improving Construction Management of an Educational Center by Applying Earned Value Technique														X
2015	EVM and Agile: Complementary Control Loops of a Project Management System	X										X			
2013	Why Do You Measure Project Performance?						X						X		
2008	Implementing EVM in an R&D Environment: From Infancy to Adolescence														X
2002	Using EVMS with COTS-based systems														X
2019	Unpacking Earned Value Management for Oil and Gas Projects														X
2016	Making EVM Work in Agile Development Projects														X
2015	A Compendium on The Application of EVM to Agile Development and The Application of Agile Development to EVM														X
2016	An overview of project data for integrated project management and control						X							X	X
2016	On the Use of Empirical or Artificial Project Data														X
2014	Earned Schedule for Agile Projects														X
2011	A time-dependent earned value model for software projects														X
2012	Earned Value Management: Adapted for use in Underground Mining Operations														X
2014	Project Success Is Elusive In All Business And Technical Domains											X		X	
2014	Performance-Based Project Management: Increasing the Probability of Project Success											X			

Year	Title	Processes										Environment			
		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2014	Effective Use of Earned Value for Controlling Construction Projects													X	
2018	Conditions of success for earned value analysis in projects											X	X	X	X
2019	Lockheed Martin Aeronautics EVMS Self Governance: Data Driven Metrics (DOM)											X		X	
2007	Project Manager Competency Development (PMCD) Framework Second Edition													X	
2016	Stakeholder C.P.R. – Crisis Project Rescue – Management of Stakeholder Issues in Troubled Projects											X	X	X	
2016	Implementing Project Controls: Preparing for the Establishment of the Integrated (Cost and Schedule) Performance Measurement Baseline	X	X												
2014	Improved cost monitoring and control through the Earned Value Management System						X								
2014	Why Earned Value Metrics Sometimes Deceive Management											X	X		
2003	A model for effective implementation of Earned Value Management methodology											X	X	X	X
2018	Methodologies for Implementing Program Controls: Strategic Methodologies for Implementing Program Controls in Change Resistant Defense Contracting Environments											X		X	
2017	Misuse of Earned Value Management Results in Erroneous Conclusions													X	
2018	Why Compliance Needs to Change											X		X	
2012	Increasing Project Controls Impact on a Successful Project													X	X
2008	Earned Value Analysis–Why It Doesn't Work						X	X				X	X		
1984	Project Management by Results											X			
2019	Use of Earned Value Management as a Communication Tool With the Project Team and the Client											X	X		
2019	Applying Earned Benefit Management: The Cost of Benefits: If You Can't Track the Allocations, You Can't Understand the Situation!													X	
2018	Applying Earned Benefit Management: Benefits Maps You Can Count On													X	
2012	Generalized Analysis of Value Behavior over Time as a Project Performance Predictor						X							X	

Year	Title	Processes										Environment			
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**1**	**2**	**3**	**4**
2018	The Standard for Organizational Project Management													X	
2019	Accurate Quantity Update: A Key for Project Management Success		X											X	
2016	Integrating Systems Engineering with Earned Value Management, Part 2														X
2016	Problems with Scheduling Practice		X											X	
2004	A Typology of Organisational Cultures											X	X		
2014	Project Controls Personnel: Finding the 'Right Stuff'												X	X	
2000	Project Performance Control in Reconstruction Projects	X	X	X		X	X								
2005	Using Weibull Analysis for Evaluation of Cost and Schedule Performance					X	X								
2001	Defining Cost/Schedule Performance Indices and Their Ranges for Design Projects		X			X	X								
2007	Quantifying the Impact of Schedule Compression on Labor Productivity for Mechanical and Sheet Metal Contractor		X												
2009	Float Types in Linear Schedule Analysis with Singularity Functions		X												
2000	A System to Control Civil Engineering Design											X		X	X
2009	Progress Monitoring of Construction Projects Using Neural Networks Pattern Recognition					X	X								
2004	Flexible Work Breakdown Structure for Integrated Cost and Schedule Control	X													
2006	A Framework for Real-Time Construction Project Progress Tracking					X	X	X							
2006	Construction Management of a Small-Scale Accelerated Pavement Testing Facility											X		X	X
2009	Project Risk Identification Methods for Construction Planning and Execution										X				
2007	Quantified Impacts of Project Change						X	X							
2004	Probabilistic Forecasting of Project Performance Using Stochastic S Curves		X	X			X								
2003	Genetic Optimization for Dynamic Project Control		X	X			X								
2007	Probabilistic Control of Project Performance Using Control Limit Curves		X	X			X								
2001	VIRCON: Interactive System for Teaching Construction Management												X	X	
2009	Probabilistic Forecasting of Project Duration Using Bayesian Inference and the Beta Distribution					X	X								

Year	Title	Processes										Environment			
		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2009	Automated CPM Schedule Generation for Early Project Planning: Methodology and Case Study		X												
2005	A Management System for Cut and Fill Earthworks Based on 4D CAD and EVMS													X	X
2004	Module-Based Construction Schedule Administration for Public Infrastructure Agencies						X				X			X	
2009	Developing Effective Visual Representations to Monitor Project Performance						X								
2007	Cost Information Model for Managing Multiple Projects		X	X											
2009	Overtime and Productivity in Electrical Construction		X												
2006	Forecasting Project Status by Using Fuzzy Logic					X	X								
2000	Probabilistic Monitoring of Project Performance Using SS-Curves					X	X								
2005	Integrated Cost and Schedule Control: Variables for Theory and Implementation					X	X								
2007	Knowledge-Based Standard Progress Measurement for Integrated Cost and Schedule Performance Control					X	X								
2002	Project Management Process Maturity (PM)2 Model											X		X	
2005	Cash Flow Forecasting Model for General Contractors Using Moving Weights of Cost Categories			X			X								
2001	Project Management in Construction: Software Use and Research Directions											X		X	
2006	Comparative Study of University Courses on Critical-Path Method Scheduling											X	X	X	
2008	Project Performance Evaluation Based on Statistical Process Control Techniques					X	X								
2003	Competing Construction Management Paradigms											X			
2006	Survey of the Construction Industry Relative to the Use of CPM Scheduling for Construction Projects											X			X
2007	Cost contingency management							X			X				
2009	Cost and schedule monitoring of industrial building projects: Case study						X	X						X	
2020	Critical Factors for Improving Reliability of Project Control Metrics throughout Project Life Cycle	X	X	X	X		X	X			X	X	X	X	X
2019	What CPI = 0.85 Really Means: A Probabilistic Extension of the Estimate at Completion						X				X				

Year	Title	Processes										Environment			
		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2019	Hazard-Based Duration Models for Predicting Actual Duration of Highway Projects Using Nonparametric and Parametric Survival Analysis						X							X	
2019	Administration of Construction Contract Interim Payments Based on Earned-Value Reduction Techniques											X		X	
2019	Bare Facts and Benefits of Resource-Loaded CPM Schedules		X												
2019	Novel Approach to Estimating Schedule to Completion in Construction Projects Using Sequence and Nonsequence Learning						X								
2019	Advanced Metrics for Construction Planning		X											X	X
2019	Project Controls and Management Systems: Current Practice and How It Has Changed over the Past Decade											X	X	X	X
2019	Exploiting Music and Dance Notation to Improve Visualization of Data in BIM						X								
2018	Metrics That Matter: Core Predictive and Diagnostic Metrics for Improved Project Controls and Analytics			X			X								
2018	Developing a Quality-Embedded EVM Tool to Facilitate the Iron Triangle in Architectural, Construction, and Engineering Practices													X	X
2018	Developing a Novel Framework to Manage Schedule Contingency Using Theory of Constraints and Earned Schedule Method		X				X								
2018	Three-Variance Approach for Updating Earned Value Management					X	X								
2018	Study on the Performance Evaluation of Construction Project Based on Matter: Element Analysis Method					X	X								
2018	Synthesis of Improvements to EVMS Key Parameters Representation											X	X	X	X
2018	Integrating BIM and Earned Value Management System to Measure Construction Progress						X								
2018	Quantifying the Impact of Change on the Progress of Construction Projects						X	X							
2018	Risk Management and the Effects on Project Success										X			X	
2018	A Review of Technology Supplemented Progress Monitoring Techniques for Transportation Construction Projects						X								
2018	Beta Index and Complexity in Schedule Performance Measurement		X				X							X	
2018	Degree of Criticality of Monitoring and Control to Project Success						X	X							
2017	Quality of Baseline Schedules: Lessons from Higher Education Capital Facility Projects		X												

Year	Title	Processes										Environment			
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**1**	**2**	**3**	**4**
2017	Enhancing Construction Project Management Education by Simulation												X	X	
2017	Project Duration Forecasting Using Earned Duration Management with Exponential Smoothing Techniques						X								
2017	Organizational-Behavior Influence on Cost and Schedule Predictability											X			
2017	Implementation of Earned Value Management in Unit-Price Payment Contracts											X		X	
2017	Five Project-Duration Control Methods in Time Units: Case Study of a Linearly Distributed Planned Value		X												
2017	Statistical Model for Schedule Prediction: Validation in a Housing-Cooperative Construction Database					X	X								X
2017	Estimated cost at completion: Integrating risk into earned value management						X				X				
2017	Generic Scheduling Optimization Model for Multiple Construction Projects		X						X						
2017	Singular-Value Decomposition Feature-Extraction Method for Cost-Performance Prediction			X			X								
2017	The Application of Mobile IT in Cost Control of Construction Phase													X	X
2017	Smart Tracking of Highway Construction Projects													X	X
2017	Infrastructure Project Formulation: A Comprehensive Approach											X			
2016	Probabilistic Evaluation of Cost Performance Stability in Earned Value Management					X	X								
2016	Customer Earned Value: Performance Indicator from Flow and Value Generation View							X				X			
2016	Allocation and Management of Cost Contingency in Projects			X							X				
2016	Estimating Cumulative Damages due to Disruptions in Repetitive Construction													X	
2016	Developing and using a new family of project S-curves using early and late shape parameters		X				X								
2016	Application of Weibull Analysis to Evaluate and Forecast Schedule Performance in Repetitive Projects					X	X								
2016	Lessons Learned from Applying the Individuals Control Charts to Monitoring Autocorrelated Project Performance Data					X	X								
2016	Cost performance as a stochastic process: EAC projection by Markov chain simulation			X			X								

Year	Title	Processes										Environment			
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**1**	**2**	**3**	**4**
2016	Quantitative Assessment of Budget Sufficiency and Resource Utilization for Resource-Constrained Project Schedules		X	X					X						
2016	Project Time Management and Schedule Performance in Mexican Construction Projects													X	X
2016	Model-Driven Management of a Construction Carbon Footprint: Case Study													X	
2016	Use of Project Schedules and the Critical Path Method in Claims		X											X	
2015	Impact of measuring operational-level planning reliability on management-level project performance		X									X		X	
2015	Project completion time and cost prediction using change point analysis						X	X							
2015	Dynamic control thresholds for consistent earned value analysis and reliable early warning										X				
2015	Study of the Stability of Earned Value Management Forecasting					X	X								
2015	Credibility Evaluation of Project Duration Forecast Using Forecast Sensitivity and Forecast-Risk Compatibility						X				X				
2015	Empirical Evaluation of Earned Value Management Forecasting Accuracy for Time and Cost					X	X								
2015	Predictability Index: Novel Metric to Assess Cost and Schedule Performance					X	X								
2015	Data Fusion Process Management for Automated Construction Progress Estimation					X	X								X
2014	Case study narrative in teaching construction project management: Earned value method examples											X	X	X	
2014	Improving forecasting accuracy of project earned value metrics: Linear modeling approach					X	X								
2014	Practical application for integrated performance measurement of construction projects					X	X								
2014	Analysis of Causes of Delay and Time Performance in Construction Projects						X				X				
2014	Sensitivity of Earned Value Schedule Forecasting to S-Curve Patterns					X	X				X				
2014	Combination of Growth Model and Earned Schedule to Forecast Project Cost at Completion					X	X								
2014	Research on Strategic Capability Maturity and Its Enlightenment to Large-Scale Contractors											X		X	

Year	Title	Processes										Environment			
		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2014	Preparing a Project Manual: A Comprehensive Project View													X	X
2014	A combined planning and controls approach to accurately estimate, monitor, and stabilize work flow					X	X								
2013	PCIM: Project control and inhibiting-factors management model						X								
2013	Toward Automated Earned Value Tracking Using 3D Imaging Tools													X	X
2013	Project Management Knowledge of Construction Professionals: Cross-Country Study of Effects on Project Success											X	X		
2013	Visual Representations for Monitoring Project Performance: Developing Novel Prototypes for Improved Communication											X	X	X	
2013	Managing the Cost of Power Transmission Projects: Lessons Learned													X	X
2013	Improved genetic algorithm for finance-based scheduling		X	X											
2013	Database framework for cost, schedule, and performance data integration														X
2013	Research on Follow-Up Audit of Government Investment Project Based on the Concept of Synergy Audit											X		X	
2012	Benefits of on-site design to project performance measures						X								
2012	Using the Earned Value Management System to Improve Electrical Project Control													X	
2012	Performance of shuffled frog-leaping algorithm in finance-based scheduling		X	X											
2012	Monitoring and Visualization of Building Construction Embodied Carbon Footprint Using DnAR - N-dimensional Augmented Reality Models													X	
2012	An analytic review of earned value management studies in the construction industry											X	X	X	X
2012	Stochastic method for forecasting project time and cost					X	X								
2011	Combination of Project Cost Forecasts in Earned Value Management			X			X								
2011	Multiobjective evolutionary finance-based scheduling: Entire projects' portfolio		X		X										
2011	Probabilistic performance risk evaluation of infrastructure projects						X				X				
2011	EVMS For Nuclear Power Plant Construction: Variables for Theory And Implementation													X	
2010	Project management information systems for pipeline design and construction - PrairieNet													X	

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		A	B	C	D	E	F	G	H	I	J	1	2	3	4
2010	Management thinking in the earned value method system and the last planner system													X	X
2010	Case Law and Variations in Cumulative Impact Productivity Claims											X		X	X
2010	Probabilistic Forecasting of Project Duration Using Kalman Filter and the Earned Value Method					X	X								
2010	Defining high-level project control data for visual information systems						X								
2010	Progress Monitoring of Construction Projects Using Statistical Pattern Recognition					X	X								
2010	Resource Performance Indicators in Controlling Industrial Steel Projects						X		X						
2010	Improving Project Performance Using the Project Health Indicator Tool											X	X	X	X

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