An Improved Earned Value Management Method Integrating Quality and Safety

Brian Briggs
Louisiana State University and Agricultural and Mechanical College

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AN IMPROVED EARNED VALUE MANAGEMENT METHOD INTEGRATING QUALITY AND SAFETY

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Donald W. Clayton Graduate Program in Engineering Science

by

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M.B.A, Columbia Southern University, 2015
M.S.C.M., Louisiana State University, 2019
August 2021
This dissertation is dedicated to all the military service members of all branches, law enforcement, firefighters, and first responders who have given the ultimate sacrifice for this great nation and Louisiana. Till Valhalla and Semper Fi!!
Acknowledgments

I am most humbly grateful and want to express my genuine thanks and gratitude to my chair, Dr. Friedland; my committee members Dr. Nahmens, Dr. Berryman, Dr. Zhu, and Dr. Loignon; and my statistics professor, Dr. Ikuma. I am humbly grateful and appreciative of your patience, guidance, and influence. I cannot thank you all enough for all you have done and for being on this journey with me. I certainly could not have achieved this without your leadership and influence.

I want to thank my Dad and Mom. To my mom who came from Mexico with a 7th-grade education, earned her legal citizenship, worked two jobs as a single mother, and emphasized the need for education. I am beyond thankful for my dad, who took on the responsibility of being a father to my sister and me. He raised me as his own and instilled in me the value to accomplish everything without quitting. His only request in payment was to achieve greatness and to be a better man and father than he was. I am still trying because he set the bar very high. My motivation, like my father who challenged me, is the unconditional love and sacrifice for my wonderful sons, beautiful daughters, and my precious grandson. I now challenge and hope that I set an example for them to never give up being the very best they can be.

I am fully blessed with all the opportunities I have been given. I am thankful for my football and powerlifting coaches, who challenged and encouraged me to be the very best in everything I do. I am most truly and deeply thankful to the U.S. Marine Corps and be forever in their debt, instilling in me a hard work ethic, the value of never giving up, and the mentality that a mission failure is never an option. I want to thank Dow Chemical for its support and encouragement. The paper represents the opinion of the author and not the opinion of Dow.
I could not have completed this most prestigious accomplishment without my loving and supportive wife, who made me countless gallons of coffee and slept on the couch numerous nights while I jabbed away at the keyboard until 2 and 3 am. My wife supported me with a smile and stood by me through all the long deployments, training away from home, remote projects, and two master’s degrees. Still to this day, she asks why I needed two.
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List of Abbreviations

ANOVA Analysis of Variance

AC Actual Cost

AEC Architectural, Engineering, and Construction

BAC Budget at Completion

BCWS Budgeted Cost of Work Scheduled

BCWP Budgeted Cost of Work Performed

CBAC Construction Budget at Completion

CDC Center for Disease Control

CEV Construction Earned Value

CMAC Construction Man-Hour at Completion

COVID-19 Corona Virus 19 variant from SARS- COV-2

CMPM Construction Management Project Model

CPI Cost Performance Index

CPM Construction Project Manager

CPV Construction Planned Value

EAC Estimate at Completion

ECBM Earned Cost-Based Management

EDM Earned Duration Management

EPA Environmental Protection Agency

ETC Estimate to Complete

EV Earned Value

EVA Earned Value Analysis
EVCM Earned Value Construction Management
EVM Earned Value Management
EVMS Earned Value Management System
FR Fire Resistant
HOV Homogeneity of Variance
ICMS International Construction Measurement Standard
IFC Issue for Construction
IPC Infection Prevention and Control
KPI Key Performance Indicator
LAO Louisiana Operations
LDH Louisiana Department of Health
LS Lump Sum
MMAD Mass Median Aerodynamic Diameter
NCR Non-Conformance Report
NFPA National Fire Protection Agency
OSHA Occupational Safety and Health Agency
PPE Personal Protective Equipment
PV Planned Value
PMB Performance Measurement Baseline
PMBOK Project Management Book of Knowledge
PMO Project Management Office
PMP Project Manager Professional
QASP Quality Assurance and Surveillance
QMP Quality Management Plan
QC Quality Control
QA Quality Assurance
QSAV Quality and Safety Actual Value
QSEV Quality and Safety Earned Value
QSPI Quality and Safety Performance Index
QSPV Quality and Safety Planned Value
SF Start Finish
SPI Schedule Performance Index
SPM Schedule Performance Management
SS Start-Start
TCONPI Total Construction Performance Index
T&M Time and Materials
TPI Total Performance Index
WASH Water, Sanitization, and Hygiene
WBS Work Breakdown Structure
WHO World Health Organization
Abstract

The construction industry invests significant time and money to improve quality and safety while reducing cost and schedule impacts. The industry has a sincere desire to improve construction project management methods to improve efficiency. Historically, quality and safety underperformances result from undermanaged quality control and safety activities. The cost and schedule impacts associated with poor quality work have always had an impact on construction operations. The unprecedented challenges and uncertainties of COVID-19 highlighted the need to improve the Earned Value Management (EVM) method within construction to reflect these quality and safety activities.

The central goal of this dissertation is to present an improved EVM method, which is named the Earned Value Construction Management (EVCM) method. EVCM integrates quality and safety as scheduled activities to capture costs as they occur. EVCM incorporates a new index-linked to quality control activities and improves the accuracy of reporting on the project in normal or pandemic construction environments.

The methodology used in this dissertation includes detailing engineering and administrative safety protocols during COVID-19, evaluating effective PPE during a pandemic, and statistically analyzing project data to demonstrate EVCM. The project data collected before and during COVID-19 of similar projects were statistically tested for significance using a one-tailed t-test. The \textit{p-values} of the three tests were all less than 0.05, indicating a significant difference was found in actual cost, the actual cost divided by budget, and total project performance using EVCM compared to EVM. The results show, despite the known increase in cost associated with the COVID-19 pandemic, the application of EVCM resulted in a statistically significant improvement in project performance.
The contribution of this dissertation is field-validated information addressing the cost and schedule impacts in industrial construction during a COVID-19 environment. Additionally, EVCM was formulated to predict cost and schedule impacts aligned with quality and safety activities. The knowledge developed in this dissertation ultimately enhances the construction industry’s ability to respond to a pandemic and incorporate quality and safety activities in a schedule to economically track and manage progress.
Chapter 1. Introduction

Construction managers have a profound desire to develop improved cost and schedule processes to better inform the management of construction projects [1, 2]. The yearning to improve cost and schedule management approaches commands the use of the most updated project management tools and techniques [3-6]. The industrial construction environment, which has been severely impacted by fiscal challenges and recently by COVID-19, requires advanced schedule performance management methods such as Earned Value Management (EVM) have increased in popularity [3-7]. The EVM method is a systematic management approach used by project and construction managers to understand the health of the project. The Earned Value Analysis (EVA) method is also used to validate a project’s overall performance indices, focusing primarily on cost and schedule. EVM and EVA are globally recognized theoretical analysis techniques that help managers overcome project and cost uncertainties using numerical data to conduct a thorough analysis of a project [4, 6-11]. However, the lack of embedded quality and safety metrics is a key limitation of EVM and EVA. This limitation is affected by quality and safety incidents that essentially shut down projects due to non-compliance and safety incidents.

In an extreme example of project, schedule, and cost uncertainties, the COVID-19 pandemic led to a complete lockdown throughout the U.S. [12]. This global event drastically impacted industrial construction along the U.S. Gulf Coast, as protocols for risk mitigation and required PPE had not been developed or implemented for construction organizations [13]. The slow and uncharted response by construction organizations during COVID-19 prompted needed for research and publication of effective protocols against COVID-19 [13]. The need for further research was evident when construction organizations had difficulty providing mitigation and COVID-19 response plans. Research and shared mitigation plans were in their infancy stages
with unsubstantiated results, with recommended safety protocols and required PPE coming from the CDC and WHO, rather than through the development of standards that had been demonstrated to be effective in a construction environment. The safety protocols and added PPE put in place during COVID-19 presented numerous challenges. The construction industry desired the knowledge of cost and schedule impacts and their effects on construction productivity.

The urgent demand to enhance construction projects’ return on investment is a priority for stakeholders and owners [14], regardless of external circumstances including the COVID-19 pandemic. There is anecdotal evidence that poor quality in projects leads to safety implications [15]. The need for improved quality in construction projects has a considerable impact on safety as synchronized relationships of the two are required to be effective [15]. Quality Control (QC) is a vital conformance and inspection process in all construction projects [16, 17]. A good QC inspection plan increases conformance to technical specifications and prevents construction errors and installation of defective materials and equipment[18, 19]. However, quality performance is traditionally not measured through EVM methods, nor does the schedule commonly capture planned safety and quality control activities for a project.

Traditional schedules and the project schedule performance index (SPI) and cost performance index (CPI) calculated through EVM and EVA neglect the importance of silent construction impacts such as quality and safety [3, 20, 21]. The issues of non-conformance and poor quality during construction lead to increased cost and duration [22]. Over the last decade, the global construction industry has placed a great deal of emphasis on managing quality and costs associated with poor quality [18, 23, 24]. The cost impacts of quality and safety in construction have increased dramatically and can account for 30% of the overall construction cost overruns [22]. While navigating the tremendous challenges and uncertainties of the COVID-
19 pandemic, the need for improved construction management tools that are more comprehensive of the realities and triggers that need to be managed to ensure quality projects are delivered on time and within budget has been even more prevalent.

1.1. Problem Statement

Current EVM and EVA construction management tools do not address scheduled quality and safety construction activities. During the COVID-19 pandemic, the need to understand the cost and schedule impacts of the unprecedented safety controls was evident. An improved EVM method that integrates and measures quality and safety performance in a construction environment is needed. Further, the effectiveness of the improved EVM method must be measured.

1.2. Goal and Objectives

The central goal of this dissertation is to improve construction project management methods, especially during uncertain conditions such as the COVID-19 pandemic, by explicitly integrating quality and safety activities. To address this goal, an improved EVM method – the Earned Value Construction Management (EVCM) method – is developed. As a step toward achieving this goal, the following objectives are undertaken:

- Describe industrial construction safety policies, best practices, and associated cost and schedule impacts in a pandemic.
- Develop and demonstrate the value of EVCM using real-time industrial earned value (EV) data.
- Demonstrate the importance of EVCM through statistical analysis of industrial EV data before and during the COVID-19 pandemic.
The construction industry requires and values information addressing the cost and schedule impacts in industrial construction during a COVID-19 environment, where no data are available. However, despite the need to better understand cost and schedule impacts during this recent event, the industrial construction industry has long needed a way to anticipate cost and schedule impacts of quality and safety aspects of a project. Above the pandemic-associated needs, there is tremendous value in improving EVM to meet general construction project management needs. Documentation of prescribed safety protocols and PPE during a pandemic is expected to improve the response of construction organizations in future epidemics and pandemics.

1.3. Dissertation Scope

The study’s scope is to develop and apply an approved method of EVM to a simulated case study of industrial construction projects. This research addresses the additional safety protocols and personal protective equipment required during a pandemic, as well as the cost and schedule impacts to industrial construction projects from implementing the safety protocols and best practices. The study compares the significance before and during COVID-19, using statistical analysis of the performance indices. The scope of the study also demonstrates the cost and schedule impacts of the COVID-19 pandemic environments.

The contribution of this dissertation is the enhancement of EVM to explicitly address quality and safety activities, resulting in a more realistic representation of cost and schedule metrics, which can be used to monitor project progression. The EVCM method is validated using scenario-based simulation and statistical testing. In addition to providing an improved method, this dissertation also contributes to providing all effective risk mitigation and safety protocols that protect and reduce the spread of a virus in a construction environment in a pandemic.
environment. The project data tested and evaluated consists of practiced safety protocols in Louisiana during COVID-19, Project data of four furnaces before COVID-19, and four furnaces during COVID-19.

1.4. Limitations

The research and data focus on typical construction within Gulf Coast states, predominantly Louisiana. The data obtained are from an industrial construction environment located at a chemical plant in Louisiana. The research and discussion within this dissertation are presented from the facility owner’s perspective but can be applied in any construction environment. The project used in the dissertation has an estimated value of $30 million. The application of the EVCM method prescribed in the dissertation is more effective if the skill and experience level of the project team is above a basic understanding level of EVM. The description and details of schedule performance management are limited to the use of industry-standard scheduling software. The construction project data is limited to eight furnaces located in Louisiana. The variances and means were statistically tested with no other statistics applied using JMP software. The analysis in Chapter 3 compares project data to a simulated quality control index to show impacts to the overall performance index. Chapter 4 compares data collected before and during COVID-19 where the contractors were the same but the inefficiencies in execution changed. Further research and project data from different construction environments would be expected to improve the robustness of the results.

1.5. Organization

The following chapters organize this dissertation: Chapter 1 introduces an overview of the topics, goals, and objectives, and the study’s scope and significance. Chapter 2 presents safety protocols, practices, cost, and schedule impacts related to COVID-19. Chapter 3 explains
Earned Value Construction Management (EVCM), which is an improved Earned Value (EV) method for industrial construction. Chapter 4 presents the application of the improved EVCM method in a simulated case study using project performance data and statistical analysis. Finally, Chapter 5 presents the conclusions and summary of the chapters presented in the dissertation.
Chapter 2. Industrial Construction Safety Policies, Best Practices, and Associated Cost and Schedule Impacts in a Pandemic

2.1. Introduction

During COVID-19, the industrial sector still needed to execute construction projects to safely maintain reliable equipment that would lead to severe consequences and impact safe operations if not maintained or repaired. To allow construction workers to return to work, there needed to be infection prevention and control (IPC) guidelines that incorporated federal and state guidelines to prevent the spreading of COVID-19. Until COVID-19, there were no impactful IPC guidelines in place for industrial construction. The construction workforce experiences working through cold and flu season due to needing to earn a living. The compensation of construction laborers only applies to actual hours worked. If they call in sick, they do not receive compensation.

This chapter outlines safety processes and protocols during COVID-19 from January to December 2020. The industrial projects discussed in this dissertation center around mechanical, piping, structural steel, valves, process equipment, electrical, and instruments typical of industrial construction. From a safety aspect, the spread of COVID-19 at Dow in Louisiana was controlled and mitigated to an astonishingly low number compared to statewide and gulf coast cases. In 2018, there were about 7.5 million construction workers employed in the U.S. [25]. Construction labor accounts for approximately 5% of U.S. Labor [26]. Construction projects, big or small, are inherently dangerous work environments, and construction workers are accustomed to working in these hazardous conditions.

The IPC from each organization needed to address how they would comply with the Dow Louisiana Operations (LAO) COVID-19 policy. The submission of the contractor’s IPC was time-sensitive and critical as we saw cases and outbreaks increasing in Louisiana from March to
the end of July among construction workers [10]. Compliance and obtaining the required PPE proved challenging for most contractors in the earlier months of the COVID-19 lockdown. In March 2020, shortages of N95 protective masks were becoming unavailable and designated only for healthcare and first responders [27].

There are always considerable challenges in improving the safety culture by changing and adding additional safety protocols. The unknown impacts of COVID-19 and how it quickly spreads led the industry to institute essential safety protocols. This study addresses the problem statements: (1) what additional safety protocols and personal protective equipment requirements and (2) what are the cost and schedule impacts to industrial construction projects resulting from implementing safety protocols and added PPE? This chapter’s objective is to provide the results of a simulated case study to address the problem statements and validate the cost and schedule impacts.

With the addition of COVID-19 as a critical factor in construction, the industrial construction sector is faced with more challenges to overcome and mitigate. During COVID-19 and the challenging conditions it presents, the industrial industry still required construction and maintenance projects to sustain plants’ safety operations. The Department of Homeland Security declared that chemical plants as essential facilities and could continue EPA compliance projects. The COVID-19 pandemic added social distancing, pre-entry screening, additional personal protective equipment (PPE), and vital hygiene methods to current construction safety practices. While complying with these added safety protocols, the industrial construction industry cannot forget that it has a distinct reputation for high incident rates and less than desirable safety performance.
2.2. Background

On December 31, 2019, the WHO received the first initial reports of clusters of SARS-CoV2, which causes COVID-19, from Wuhan, China [12, 28]. WHO declared COVID-19 an international public health emergency by January 30, 2020 [12, 29]. On March 11, 2020, the WHO officially announced COVID-19, a global pandemic [12, 28].

Shortly after, the Governor of Louisiana declared a state of emergency on March 11, 2020 [30]. The initial cases in Louisiana started in six parishes, one of which is New Orleans parish. This parish saw the most initial cases resulting from large gatherings of tourists worldwide participating in Mardi Gras during February 2020 [31]. The CDC also reported this large gathering of over 1 million participants played a prominent role in the early U.S. spread of COVID-19 [31]. Since Mardi Gras, Louisiana saw increased cases reported by the Louisiana Department of Health (LDH). As of July 25, 2020, LDH had reported 94,892 cases and 3,462 deaths [30]. The U.S. is one of the few countries that have recorded the most diagnosed cases worldwide [32]. A study published in April 2020 reported that 8.3% of the 5.9 million construction workers during the pandemic would be exposed once a month [33].

According to Louisiana Economic Development (LED), more than 300 industrial facilities are located in Louisiana [34]. Of these 300 facilities, Dow Chemical is in six sites across Louisiana. Dow Chemical produces more than 50 chemical products to make respirators, PPE, pharmaceuticals, food-grade plastics packaging, and household goods [34]. In Louisiana, Dow Chemical was considered a critical infrastructure site by the U.S. Government. Essential and critical infrastructures defined by the Department of Homeland Security (DHS) are Chemical, Communications, Energy, Dams, Emergency Services, Financial Services, and Food and Agriculture. Given the DHS criteria, Dow received approval to continue operations and
continue reliability, environmental, health, and safety construction projects. Dow Chemical, specifically for COVID-19, published new safety policies and procedures for entry screening, social distancing measures, quarantining infected or at-risk personnel, mandated additional PPE for all personnel to perform work at Dow LAO. The dissemination to all contractors of the new Dow COVID-19 policy and procedure occurred in March 2020 at Dow LAO. The next step was for the contractors to review and digest the new policy and then provide Dow with their COVID-19 Social Distancing and PPE plan. The approval of their plan had to occur before being cleared to work. Also, contractors are required to pass a medical pre-screening at the badging entry locations. The pre-screening of contractors consisted of temporal thermometer reading and questioning if they have any of the symptoms in Table 2.1. Those acknowledging a symptom are required to quarantine and denied entry.

Table 2.1. COVID-19 Symptoms [12]

<table>
<thead>
<tr>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fever or feeling feverish (chills, sweating)</td>
</tr>
<tr>
<td>New cough</td>
</tr>
<tr>
<td>Difficulty breathing</td>
</tr>
<tr>
<td>Sore throat</td>
</tr>
<tr>
<td>Muscle aches or body aches</td>
</tr>
<tr>
<td>Vomiting or diarrhea</td>
</tr>
<tr>
<td>New loss of taste or smell</td>
</tr>
<tr>
<td>Congestion and running nose</td>
</tr>
<tr>
<td>Traveled outside the country</td>
</tr>
</tbody>
</table>

2.3. Simulated Case Study

Company ABC Construction, LLC, is bidding on a 4-week project working four days, 10 hours each day. The project scope is installing 1,000 linear feet of pipe, welding of flanges for bolt-up connections, installing valves and instruments, civil work for structural steel, tubing for air, and conduit for cabling. The project is a compliance project and requires immediate mobilization within ten days of the accepted bid. The bid package specifies that the company
must practice social distancing, sanitization, and hygiene, be fit tested and have the required PPE per the Dow COVID-19 Policy. The company’s estimator would need to estimate as he would any other job to establish a baseline cost. From this baseline cost, he would need to add the additional itemized costs for COVID-19 compliance. Table 2.2 provides baseline project costs before the COVID-19 environment while Table 2.3 itemizes COVID-19 costs for reference.

Table 2.2. Baseline Four-Week Estimated Project Costs for 40-Man Crew

<table>
<thead>
<tr>
<th>Labor and Equipment</th>
<th>QTY</th>
<th>Unit Cost</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fit Test</td>
<td>1</td>
<td>$45</td>
<td>$45</td>
</tr>
<tr>
<td>N95 Respirator</td>
<td>1</td>
<td>$45</td>
<td>$45</td>
</tr>
<tr>
<td>P100 Filters (3 prs)</td>
<td>1</td>
<td>$40</td>
<td>$160</td>
</tr>
<tr>
<td>Face Shield Kit</td>
<td>5</td>
<td>$25</td>
<td>$125</td>
</tr>
<tr>
<td>Face Shield (4 Per)</td>
<td>5</td>
<td>$10</td>
<td>$200</td>
</tr>
<tr>
<td>Latrines</td>
<td>4</td>
<td>$150</td>
<td>$2,400</td>
</tr>
<tr>
<td>Safety Observer</td>
<td>1</td>
<td>$95</td>
<td>$15,200</td>
</tr>
<tr>
<td>QC Tech</td>
<td>1</td>
<td>$95</td>
<td>$15,200</td>
</tr>
<tr>
<td>Hand Wash Stations</td>
<td>2</td>
<td>$150</td>
<td>$1,200</td>
</tr>
<tr>
<td>Supervision</td>
<td>4</td>
<td>$95</td>
<td>$60,800</td>
</tr>
<tr>
<td>Direct Labor</td>
<td>40</td>
<td>$95</td>
<td>$608,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TOTAL</td>
</tr>
</tbody>
</table>

Table 2.3. Four-Week Estimated Project Costs for 40-Man Crew during COVID-19

<table>
<thead>
<tr>
<th>Labor and Equipment</th>
<th>QTY</th>
<th>Unit Cost</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fit Test</td>
<td>40</td>
<td>$45</td>
<td>$1,800</td>
</tr>
<tr>
<td>N95 Respirator</td>
<td>40</td>
<td>$45</td>
<td>$1,800</td>
</tr>
<tr>
<td>P100 Filters (3 prs)</td>
<td>40</td>
<td>$40</td>
<td>$6,400</td>
</tr>
<tr>
<td>Face Shield Kit</td>
<td>40</td>
<td>$25</td>
<td>$1,000</td>
</tr>
<tr>
<td>Face Shield (4 Per)</td>
<td>40</td>
<td>$10</td>
<td>$1,600</td>
</tr>
<tr>
<td>Latrines</td>
<td>8</td>
<td>$150</td>
<td>$4,800</td>
</tr>
<tr>
<td>Safety Observer</td>
<td>2</td>
<td>$95</td>
<td>$30,400</td>
</tr>
<tr>
<td>QC Tech</td>
<td>2</td>
<td>$95</td>
<td>$30,400</td>
</tr>
<tr>
<td>Hand Wash Stations</td>
<td>6</td>
<td>$150</td>
<td>$3,600</td>
</tr>
<tr>
<td>Cleaning and Sanitization Crew</td>
<td>4</td>
<td>$65</td>
<td>$41,600</td>
</tr>
<tr>
<td>Supervision</td>
<td>4</td>
<td>$95</td>
<td>$60,800</td>
</tr>
<tr>
<td>Direct Labor</td>
<td>40</td>
<td>$95</td>
<td>$608,000</td>
</tr>
<tr>
<td>Inefficiency Performance Factor</td>
<td>1</td>
<td>5%</td>
<td>$30,400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TOTAL</td>
</tr>
</tbody>
</table>
2.4. Methodology and Best Practices

The research questions motivating this work are: what science-based safety protocols are appropriate for limiting the workplace spread of COVID-19 for operating industrial process facilities? Following the implementation of these protocols, what are the costs of implementation, as generally experienced at Dow facilities in Louisiana? This study presents information on the engineering and administrative controls practiced at Dow in Louisiana. The engineering controls are the safety protocols put into place by Dow LAO for site entry, pre-screening, quarantine, social distancing, personnel protective equipment (PPE), and sanitizing practices during the COVID-19 pandemic. During the initial stages of the COVID-19 pandemic, we learned that social distancing, PPE, disinfecting, and sanitization are highly recommended to mitigate against outbreaks and infection to workers [35]. This practice’s purpose is that the virus can live on surfaces for at least 48 hours [35].

The administrative controls are the policies and procedures issued to all contractors in the engineering controls practice. These administrative controls are very similar to IPC guidelines, which are guidelines to reduce the transmission of infections [36]. Another administrative control implemented by Dow was to reduce the number of administrative workers in the physical workplace. This administrative control allowed individual employees to work from home. Also included are individuals considered to be at high risk of contracting COVID-19 and develop severe symptoms that would degrade their health [37].

The rationale for each protocol is presented in this study, followed by a description of the best practices implemented and measures for associated cost and schedule impacts. Details discussing reasonable cost and schedule impacts to an industrial construction project are provided based on implementing the safety protocols in spring and summer 2020. A hypothetical
The project case study demonstrates the estimation of the additional cost associated with additional PPE and Fit Testing requirements in a COVID-19 environment in Louisiana.

The contribution of this study is to provide relevant information on successful construction safety policies and practices and recommended PPE that was instrumental in mitigating the spread of COVID-19 in an industrial construction environment in Louisiana. Considering the discussed safety policies and procedures can be applied in the gulf coast region at other industrial facilities as a foundation during a pandemic. The gulf coast region has similar climates to Louisiana and the demographics of transient construction workers. These policies and procedures should have a high consideration to be used during the cold and flu season to mitigate outbreaks.

On average, the cold and flu season can impact one person’s absenteeism for three days [38]. A study conducted by Xue et al. from 1998 to 2006 predicted that the cost of working days lost in productivity was, on average of $231 million [38]. The prescribed social distancing and recommended PPE, such as face shields and goggles, can reduce work productivity due to illness and viruses while mitigating outbreaks [39]. The process and valuable contribution of this chapter are to propose hygiene and disinfection applications that were effective against COVID-19 [39].

2.4.1. COVID-19 Dow LAO Entry Procedures

In March of 2020, Dow LAO imposed several entry procedures for all personnel gaining entry to the site, Dow personnel included. The CDC and the state of Louisiana established a predetermined number of people who can work on Dow LAO as declared as essential and infrastructure. The number of contractors that entered the site daily from March to June peaked into the thousands. The number of contractors concerned Dow, but the projects were of priority.
The number of cases reported in Louisiana for industrial work (692), construction sites (79), and worksites (291) is a total of 1,062 cases, refer to Table 2.4 [30]. The environments that displayed the most cases and outbreaks were bars, food processing, and industrial sites [30]. Industrial and construction worksites reported a total of 771 cases [30]. In Table 2.4, the total cases reported in the listed categories is 3939. The industrial and construction sectors were 19.5% of the total cases reported.

Table 2.4. Number of COVID-19 Cases in Louisiana as of 12/22/2020 [30]

<table>
<thead>
<tr>
<th>Setting</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar</td>
<td>537</td>
</tr>
<tr>
<td>Casino</td>
<td>295</td>
</tr>
<tr>
<td>Child Daycare</td>
<td>147</td>
</tr>
<tr>
<td>Construction Site</td>
<td>79</td>
</tr>
<tr>
<td>Food Processing</td>
<td>923</td>
</tr>
<tr>
<td>Gym/Fitness</td>
<td>62</td>
</tr>
<tr>
<td>Industrial Setting</td>
<td>692</td>
</tr>
<tr>
<td>Office Space</td>
<td>157</td>
</tr>
<tr>
<td>Other Worksite</td>
<td>291</td>
</tr>
<tr>
<td>Recreation</td>
<td>36</td>
</tr>
<tr>
<td>Religious Services/Event</td>
<td>335</td>
</tr>
<tr>
<td>Restaurants</td>
<td>304</td>
</tr>
<tr>
<td>Social Events</td>
<td>81</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3939</strong></td>
</tr>
</tbody>
</table>

2.4.2. Dow LAO Best Practices During COVID-19

2.4.2.1. Stage 1: Resource Planning

Stage 1 consisted of identifying the number of contractor resources based on project priorities. There were restrictions on how many personnel could be onsite at a given time. State and federal guidelines imposed these restrictions to comply with COVID-19. Dow had numerous meetings with contractors and stakeholders to determine an agreeable workforce to support the project list. The approved projects had to meet state, federal, and Dow criteria. Based on approved projects that met the requirements, a review of an approved safe work plan for each
The project was done by Dow. The work plans from the contractors had to provide the number of personnel, equipment, subcontractors, as well as social distancing and PPE procedures. The site leadership managed the total number of personnel allowed at Dow LAO. Any additional resources had to go through a request and approval process. The resource numbers were kept to a minimum and validated to ensure that social distancing compliance was not hindered by too many personnel in one area. For the pre-screening and contraflow through the entry gates to be successful, the data of allowed personnel assisted on the entry schedule. The term used is activity-based sourcing for each project. Activity-based sourcing is a term used to assign critical resources to each activity in the schedule’s work breakdown structure. The activity-based planning also includes equipment, tools, and materials needed by the contractor that is not Dow provided.

2.4.2.2. Stage 2: Contractor Prescreening

Stage 2 began once Stage 1 was complete. In Stage 2, Dow advised each contractor the maximum number of employees they could have onsite at any given time. The contractor was responsible for identifying which employees would be part of the approved list authorized by Dow. Each company screened its employees internally before submitting the named list to Dow. For example, if contractor A were permitted to have 45 workers, the 45 employees were then pre-screened by contracted health professionals and tested for COVID-19 symptoms before entry. The employer would advise Dow that all personnel on their list passed the medical pre-screening and not symptomatic for COVID-19. The mitigation of ensuring that non-infected personnel gained entry is a critical step and objective of this pre-screening process. Dow would be conducting their pre-screening as each vehicle entered with passengers. The purpose of requiring employers to screen their employees before entering the site is to identify anyone
infected or has symptoms. This would allow them to have ample time to replace the employee and prevent an infected employee from showing up at the Dow pre-screening. This is also a practice for preventing the spread and an outbreak at the site.

2.4.2.3. Entry Schedule and Locations

Dow designated separate locations and times in which entry was allowed. Entry point 1 was for essential Dow personnel such as security, medical, leadership, fire safety, and designated personnel. All essential support staff was allowed to enter during their given time. Entry point 2 was for suppliers, vendors, and contractor personnel. Entry point 2 had designated times for contractor entry on a staggering time of entry. The rationale behind this is to allow Dow security to maintain contraflow and traffic control through these entry points. When exiting the site, all personnel exited their designated entry point during regular working hours. The exiting of personnel after hours exited through another designated exit point.

At each entry point are security guards and medical screeners, each with a digital temperature thermometer. Upon entry, all passengers had to have an approved facial covering and exit the vehicle one at a time to be screened. Those contractors who use bus and passenger van entry must have all passengers wear an approved facial covering and use staggered seating. The staggered seating is a requirement for maintaining social distancing. The medical person at the entry point boards the bus to conduct the pre-screening. For vans, each passenger must exit one at a time except for the driver. For single cab trucks, there can only be two passengers. For extended cab trucks and four-door vehicles, there can only be four people in those vehicles.

2.4.2.4. Entry Prescreening

All personnel, including contractors, who gain entry to Dow LAO undergo a temperature check. All personnel attempting to gain entry must have a temperature reading less than 100.4
degrees and be asked all pre-screening symptoms referenced in Table 2.1. A "yes" response for any of the pre-screening symptoms and a temperature higher than 100 degrees results in denied entry. In addition to denying entry, the person must quarantine for a minimum of 14 days. Before anyone can return, they must be free of any of the symptoms listed in Table 2.1 and provide a negative COVID-19 test result from any designated testing center. Dow LAO medical staff reviewed the case and provide their recommendation. The medical profession has defined the best way to control the spread of COVID-19 to have strategies for early diagnosis, reporting, isolation, and testing [40]. The medical staff, occupational health, and safety professionals at Dow have also influenced the requirement for pre-screening at the entry locations.

2.4.3. Cost and Schedule Impacts

The cost of executing this procedure is substantial and not within the normal budget. Dow, per the new COVID-19 policy, required the staffing of medical screening technicians. The number of medical screeners needed to support the entry schedule is a minimum of (8) medical screeners working 12hrs a day, seven days a week. This potential cost could be approximately $760,000 for three months to support eight screeners. The cost impact is minimal if it turns away anyone infected to spread and initiate an outbreak. Any site’s impact by having to shut down operations and projects can lead to a cost impact in the millions per day. The schedule impacts are just as impactful. Most compliance projects have no later than a date to comply and are planned by phases. These planned phases centered around specific dates that must meet compliance dates and outage windows. The compliance projects directed by federal and state agencies provide the compliance dates. Those projects executed during an outage window are essential maintenance and construction projects. The projects and turn-around activities are normally planned and scheduled years in advance.
2.4.4. Quarantine and COVID-19 Test Procedure

2.4.4.1. Rationale

The definition of quarantine by public health professionals is to separate persons or communities who have been exposed [41]. Also, the definition of isolation is to separate persons known to be infected [41]. Quarantine and isolation can be voluntary or involuntary [41]. Per the CDC website, severe acute respiratory syndromes fall into involuntary quarantine diseases [41]. It is highly recommended and emphasized that anyone who has any flu-like symptoms should stay home to prevent exposure and spread [42]. As mentioned earlier, Dow avoided this initial measure as much as possible by having the contractor do a pre-screening within their company employees.

2.4.4.2. Dow LAO Best Practices

All Dow and contractor employees, who through the entry pre-screen with a temperature of 100.4 degrees or answer “yes” to the entry medical questionnaire, are required to be quarantined for a minimum of 14 days. The 14-day quarantine time frame must be consecutive with no symptoms. Upon completion of the quarantine with no symptoms, the employee must inform their immediate supervisor. Contractors reported all quarantine or symptomatic employees to their Dow Contract Administrator. All personnel must be cleared through Dow Medical to return to the site for work. The site manager for that employee submits a request to the Dow Contract Administrator, acknowledging the employee has been quarantined and has no symptoms. The employee can submit a copy of their negative results to Dow Medical. Dow employees must clear through their supervisor and Dow Medical. Dow employees with a negative test result are required to submit a copy to Dow Medical. At any given time that a Dow employee or contractor has any symptoms, they must report it and quarantine for 14 days. Even
if the employee has a negative test result but displays any of the symptoms referenced in Table 2.1, they must quarantine.

2.4.4.3. Cost and Schedule Impacts

Any contractor with an outbreak is required to quarantine those infected and anyone in general contact. The impact of this scenario is impactful for those projects that have a small crew. For example, a 4-week compliance project with a crew size of 14 direct laborers and five indirect leadership would be postponed for a minimum of two weeks. Let us assume the fines and penalties from the EPA is $1,000 per day. For one person to be infected would potentially shut that one project Down for 14-days. The penalties would cost $14,000 and the daily profits to Dow for not bringing that section unit up to compliance. The cost impacts at this point would be in the millions of dollars. The schedule impacts other successor projects that cannot begin until this one is complete. It is a chain reaction that also leads to more cost impacts. The impacts on morale within the laborers are also a concern and have a monetary impact as well. Those workers who are quarantined and not infected are without pay till they are allowed to return to work. This impacts at about $60 per hour worked up to 40 hours and $90 per hour for overtime for a welder. The employee’s cost is $4,800 for the two weeks of lost pay for a 40-hour workweek. For a 50-hour workweek, this is an additional $1,800 for a total of $6,600 of lost wages. Those employees who sustain that loss of wages may potentially go work elsewhere.

2.5. Social Distancing and Personnel Protective Equipment (PPE)

2.5.1. Rationale

The acceleration of COVID-19 caused occupational hygienists to introduce simple and effective measures such as social distancing to reduce exposure [43]. In addition to healthcare employees, other workers, such as construction, are at risk of getting COVID-19 [43]. The
standard PPE for all work in a process area is wearing steel toe boots, long-sleeve fire resistance (FR) shirt and pants, a hard hat, safety glasses, and chemical protective goggles. The FR shirt and pants must be CAT Level 1 and NFPA 2112 compliant. As of March 2020, COVID-19 appeared in 76 countries [43]. The secretion of microbial pathogens from an infectious person’s respiratory tract normally passes in the air through sneezing and coughing [44]. Through violent respiratory events such as coughs and sneezes, the spread of infectious respiratory diseases occurs [45]. The information we have eludes us to prescribe certain PPE at certain social distance requirements. Through occupational hygienists and safety professionals’ input, Dow has prescribed mandatory PPE at certain distances, per Table 2.5. The distance is a factor as coughing and especially sneezing by an infected person can release many airborne droplets where the nuclei contain COVID-19. The inhaling of these infected nuclei is one of the primary transmissions of COVID-19.

Table 2.5. PPE Requirements for Social Distancing

<table>
<thead>
<tr>
<th>Equipment</th>
<th>6ft</th>
<th>6ft to 3ft</th>
<th>3ft to 0 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fit Test</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N95 Respirator</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Face Mask</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Face Shield</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Steel Toe Safety Boots</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Safety Glasses</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hard Hat</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Safety Gloves</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>FR Shirt and Pants</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

2.5.2. Best Practices

From what we have learned in a short period, the infectious disease COVID-19, related to SARS-CoV-2, can be spread through the small and large droplets from an infected person [46, 47]. Large droplet expulsion is generally measured with a mass median aerodynamic diameter
(MMAD) [48]. Large droplets are greater than 10 micrometers while particles with MMAD less than 10 micrometers are defined as droplet nuclei [48]. In Figure 2.1, we learned the distance in which the droplets travel. The droplets from a cough can travel as far as 2 meters or 6.6 feet [46, 47]. The droplets from a sneeze can travel farther than a cough, up to 6 meters or 19.8 feet [46, 47]. The alarming information is that the cough has about 3,000 droplets and a sneeze has about 40,000 droplets [46]. The exhaling of droplets can travel up to 1.5 meters or 4.11 feet before descending to the ground [46, 47].

![Figure 2.1. Cough and Sneeze Travel Distance](image)

2.5.2.1. Within 6 Feet

Per social distancing guidelines set forth by the CDC and adopted by Dow LAO, any construction work within six feet must have an approved facial covering or face shield. The only time one can remove the facial covering is for lunch and water breaks. For lunch, the lunch tables are marked with an X and designate where personnel can sit. Staggered times are set for contractors to take their lunch break to ensure good sitting. In-office buildings, all personnel must wear an approved facial covering. The conference room tables in each conference room are designated with an X for designated seating. The posted signs on each of the conference room’s
front door detail the maximum number of people allowed. During water breaks at water stations, everyone must always sanitize their hands before and after and maintain a 6ft distance. It is essential to practice the recommended social distancing, which prevents droplet transmission [42].

2.5.2.2. From 6 feet to 3 feet

Most activities for industrial construction require personnel to work within this range of social distancing. The bolting up of pipe and valves require proximity work activities. For these activities to occur, contractors wear proper PPE is required. The required PPE for activities from six feet to 3 feet, provided in Table 2.5. While in this proximity is where the exposure and spread of COVID-19 are dangerous. Wearing a face shield in this range protects large droplets from being sprayed and reduces infection chances to others. Figure 2.1 shows that large droplets can travel up to 2 meters for a cough and up to 6 meters with a sneeze [46].

2.5.2.3. Less than 3 feet

Some activities require workers to be near one another. These activities include welding, flange bolt-ups, valve install, instrument install and terminations, safety inspections, quality control inspections, and field supervision direction. The spread of COVID-19 increases when activities require personnel to work within a range of droplets as they exit an infected person’s mouth. The recommended means to reduce the spread is to wear an N95 Respirator with P100 filters. Refer to Table 2.5 for the PPE requirements for activities done from 3 feet to 0 feet. The transmission of COVID-19 in the early evolutionary stages of the disease is not fully understood other than it potentially could spread through large respiratory droplets [49]. In a study conducted by Bartoszko et al. [49], there are no convincing data that N95 respirators are more effective than medical masks [49]. The N95 respirator with P100 filters has average effectiveness...
of 95% of inhaling or exhaling small respiratory droplets [43]. However, the need for medical masks, which are smaller and more comfortable, over N95 reduces the supply in which takes away from the health workers. Thus, N95 with P100 filters is ideal for industrial construction. The underlying issue with this requirement is the requirement for fit testing and availability.

The requirement of using N95 half-face respirators with P100 filters requires those users to be fit tested per OSHA guidelines. The fitness test is done either by qualitative or quantitative testing. In March, we saw a trend of shortages of N95 and medical masks. The U.S. news reported panic buying of N95 and medical masks, causing these shortages [50]. As a result of this panic buying, the U.S. construction industry had difficulties obtaining N95 respirators [50]. For half-mask respirators that cover the mouth and nose, OSHA requires qualitative testing. To be cleared and pass the fitness test for the N95, the wearer had to have the respirator he would be wearing. Without the N95 respirator, the contractor or employee could not complete the fitness test. The backlog of fit testing and the N95 respirator caused considerable impacts in scheduling work activities during the project planning phase. The impacts of mask shortages and required fit testing potentially increased most schedules by a week.

2.5.3. Cost and Schedule Impacts

The potential cost impact for a 40-person project that works five days a week and 10 hours per day can increase approximately $190,000 per week. For a four-week project, this cost impact is about $760,000. This is based on a composite rate of $95 per hour. This impact is detrimental as you may need to start the project installing pipe but takes longer to install due to limited welders and pipefitters who are fit tested. This delays welding, bolting up valves and installing instruments, which require an N95 respirator. The fitness test done by the local safety council had a backlog of availability to comply with social distancing in March. The cost of this
fitness test, on average, is $50, which includes medical clearance and a qualitative fit test. Table 2.3 shows the cost of a 4-week project of a 40-man crew for COVID-19 PPE.

2.6. Sanitizing

2.6.1. Rationale

It is likely that, per public health guidelines, frequent and thorough handwashing and hand sanitization, maintaining social distancing of at least 6ft, and isolation are effective risk mitigation measures against COVID-19 [40]. Recommended hand sanitizers to use on construction sites made up of either ethanol, isopropyl alcohols, and hydroperoxides, or combinations [51]. The active ingredients in commercial-based hand sanitizers are ethanol or isopropyl alcohol at about 60 to 95% concentration [51]. For many years’ alcohol-based sanitizers have been used against microbial-borne diseases [51]. However, the observation of overusing alcohol-based hand sanitizer should be observed. The overuse of alcohol-based hand sanitizers can result in toxicity through dermal absorption and become anti-microbial resistance [51].

2.6.2. Hand Sanitizing Practices

All projects at Dow LAO require an adequate number of handwashing stations and hand sanitizer. It is a requirement for all personnel to wash and apply hand sanitizer each time they use the restroom, remove their gloves before and after eating lunch, and use the water station. Hand wash stations are required every 50ft within the project area.

2.6.3. Restroom and Water Station Sanitizing Practices

In every construction project, you need water stations and restrooms for the workers. These locations usually are socializing points. Being in a social distancing environment requires that only one person at a time and must maintain a 6ft separation. Also, the workers must wash
or sanitize their hands before and after getting water. No plastic bottles or containers are permitted. It is allowed to use paper cones or cups but must be discarded after use. The practice of good drinking water, sanitization, and hygiene (WASH) interventions help prevent diarrhea due to fecal contamination due to poor hygiene [52]. In addition to preventing diarrhea, WASH is also important prevention of COVID-19 [29]. Handwashing with water and soap (HWWS) and WASH practices serve as a critical defense in the transmission of COVID-19 [29].

2.6.4. Van and Bus Sanitizing

The vehicles that transport construction workers to the project sites require sanitization before and after use. The use of an approved disinfectant on all surface areas of the seat and areas that are touched is necessary to prevent the spreading of COVID-19 [53]. It is suggested that enhanced hydrogen peroxide be used for large surface areas that need to be disinfected [53]. It is recommended to properly ventilate while disinfecting for a minimum of 5 minutes and allow adequate drying time [53]. To meet these sanitization requirements requires having additional personnel whose primary task is to clean and sanitize. These resources depend on the project’s size and the frequency of sanitizing per the site occupational hygienist and site policy.

2.6.5. Sanitization Costs

For projects at Dow LAO, an average of 4 helpers is required to complete the requirement. The increased resources are in addition to normal resourcing to support the project. The additional cost is about $52,000 for a 4-week project that could be added to the project. The cost of a handwash station is around $150 per week for each. This includes the daily maintenance of these handwash stations. The cost of restrooms is also $150 per week for each restroom. Table 2.6 provides the estimated cost for sanitization during a COVID-19 project. The cost per Table 2.6 could also be used for flu and cold season if desired by the project site.
Table 2.6. Cost of Sanitization for COVID-19 versus non-COVID

| Labor and Equipment                  | COVID-19 Costs | Non-COVID-19 Costs |  |
|-------------------------------------|----------------|--------------------|  |
|                                     | QTY | Cost Per | TOTAL | QTY | Cost Per | TOTAL |  |
| Latrines                            | 8   | $150     | $4,800 | 4   | $150     | $2,400 |  |
| Safety Observer                     | 2   | $95      | $30,400 | 1   | $95      | $15,200 |  |
| Hand Wash Stations                  | 6   | $150     | $3,600 | 2   | $150     | $1,200 |  |
| Cleaning and Sanitization           |     |          |        |     |          |        |  |
| Crew                                | 4   | $65      | $41,600 | 0   | $65      | $ -   |  |
| Sanitization Supplies 1Gal         | 16  | $30      | $480   | 4   | $30      | $120  |  |
| Hand Sanitization 1Gal             | 24  | $30      | $720   | 8   | $30      | $240  |  |
| **TOTAL**                           |     |          | **$81,600** |     |          | **$19,160** |  |

2.7. Discussion

In March 2020, Dow LAO experienced a critical outbreak that impacted over 14 contractors on an essential project. This project was halted and adversely affected for about two weeks. This event fast-tracked the need for stricter social distancing enforcement and more aggressive PPE for protecting the spread of COVID-19. This event also triggered the necessity of improved sanitization practices. What Dow also learned is that quarantine practices work against spreading and outbreaks of COVID-19. Since the outbreak of that one event, all positive cases were isolated to individual cases only.

From Table 2.2 and 2.3, we calculate a difference of $119,225 from the base estimate. The increase is costing the project an additional cost of about $29,806 per week. This is important for the contractor, and the owner should the project go past the 4-week duration. This is either a negative cost to the contractor or a charge to the owner. We can also calculate the burn rate per week for the crew’s 4-week project in Table 2.2, which is $205,565. The impact is calculated to $1,093.88 per man-day on a 40-hour workweek. This is important when determining if more resources are needed or reducing the workforce to control cost overruns. We also conclude that COVID-19 adds six resources to your workforce to support additional safety oversight and clean and sanitize water stations.
If the contractor and their estimator are not careful, the estimated cost can easily impact the contractor by not capturing increased costs incurred by COVID-19. The cost impact requires the contractor to seek a change order and lose the owner’s confidence in their estimating. For the PPE and Fit Test requirements per Table 2.7, the cost is $12,600 for a crew size of 40 for a 4-week project. This PPE is vital in mitigating the spread of COVID-19 and is important in complying with safety processes during a pandemic.

Table 2.7. COVID-19 PPE and Fit Test Costs

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Crew Size</th>
<th>Unit Cost</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fit Test</td>
<td>40</td>
<td>$45</td>
<td>$1,800</td>
</tr>
<tr>
<td>N95 Respirator</td>
<td>40</td>
<td>$45</td>
<td>$1,800</td>
</tr>
<tr>
<td>P100 Filters (6 per)</td>
<td>40</td>
<td>$160</td>
<td>$6,400</td>
</tr>
<tr>
<td>Face Shield Kit</td>
<td>40</td>
<td>$25</td>
<td>$1,000</td>
</tr>
<tr>
<td>Face Shield (4 per)</td>
<td>40</td>
<td>$10</td>
<td>$1,600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$12,600</strong></td>
</tr>
</tbody>
</table>

2.8. Conclusion

The COVID-19 pandemic reminds us of all the emerging challenges that infectious pathogens impose on communities and countries [54]. It is also a reminder of our need to practice good hygiene, wash our hands, sanitize, and social distance in an infectious or pandemic environment [54].

The PPE needed for a small project of 40 personnel cost about $7-10,000. The cost and schedule impacts for inefficiencies can be an extra week and a cost of about $190,000. With only 55.4% of all small businesses in the U.S. still operating and only having about $10,000 operating revenue per week, additional costs can be detrimental [55]. As a result of practicing the protocols described in this study, social distancing, wearing proper PPE, sanitizing practices, and medical pre-screening Dow LAO only saw about 132 positive cases of COVID-19. Of the 771 industrial and construction cases reported, Dow LAO is 17%, but only 3% of the total cases reported in
Louisiana. Of these cases, all have returned to work once cleared through testing and quarantine. These low numbers are indicative of good safety processes and practices.

The Dow LAO COVID-19 policy positively impacted the number of cases which reduced the number of cases as compared to the rest of the state. Dow’s COVID-19 policy positively contributed to reducing the spread of COVID-19 in a construction environment. We also saw cooperative efforts from owner to contractor in emphasizing a safety culture change that benefited both parties. Like every plan and strategy, there is always room for improvement. However, what has been learned from the safety processes during this pandemic establishes a starting point for the next wave of COVID-19 or the next pandemic. There are discussions that the current practices are warranted not just for a pandemic but also for outbreaks during flu season.

There is a safety requirement by the owner and the contractor to protect their employees and others when an infectious virus or disease is present. Pandemic is not the only outcry to practice possible safety measures to protect everyone on a project site. However, the COVID-19 pandemic brought light to some necessary improvements for a safe working environment within the industrial construction environment. The contribution of the information shared within this study serves as a foundation for industrial construction projects that encounter the next wave of COVID-19 or another similar pandemic. This information is important to project budgets and estimators during a pandemic such as COVID-19. The estimated composite rate also increases but is not captured in the initial estimate.
Chapter 3. Earned Value Construction Management Method

3.1. Introduction

Construction projects in the industrial environment are complex and prone to field construction complications due to cost, schedule, and quality [23]. Project success is measured by applying key performance indicators (KPIs), that include cost, time, quality, safety, and stakeholder contentment [3-6, 21, 56]. Project uncertainties traditionally often involve engineering errors, weather delays, and cost overruns due to quality and safety that adversely affect the project [23]. The early applications of EVM and EVA originated by the Department of Defense to appraise projects’ financial performance [1, 5, 6, 57]. EVA has been an application used in the project management industry since the 1960s [1, 3, 5-7, 21].

Since its inception, minor improvements have been made to EVM, but these still do not include cost and schedule impacts associated with quality and safety. EVM and EVA’s origins utilized three key metrics to evaluate the project’s health [57]. EVM uses the sequence of planned value (PV), earned value (EV), and actual cost (AC) to present a quantitative warning of the condition of the project [1, 3, 5, 6, 9, 21, 57]. Project and construction managers traditionally use the EV method of analysis throughout the life cycle of the project but use an internal method to address quality and safety.

The contribution of this chapter is to provide an improved method of EVM to address the shortfalls of not explicitly including activities related to safety and quality in a schedule. The improved method requires quality activities from the ITP and safety activities from the safety audit plan to be included. These activities for quality, safety, and construction performance are tracked and reported. The method is validated against a simulated quality and safety control index to show the impact on the total construction performance index.
The improved EVM method aligned with industrial construction includes quality control and safety performance [58]. There is an urgent demand to improve cost and schedule impacts related to quality and safety. The second contribution is comparing real-life project data using the traditional EVM and new EVCM utilizing EVA principles to support or reject critical decision corrective actions in industrial construction projects. These contributions are added tools for the construction project management team to improve and maximize the stakeholders’ return on investment.

The case study presented shows the value of the EVCM method compared to EVM using statistical testing and data. The study provides examples of how to add quality control and safety activities to your schedule. The EVCM method introduces new processes of data collection and indices for accurate project progress reporting. The case study demonstrates how quality control of failed inspections adds time and cost to a project. The cost impacts of a work stoppage due to safety mishaps and safety near misses are also included in the QSPI. The new EVCM method and formulas introduced enhance construction project management techniques in the EVA of a project. They are simplified so that any level from the foreman and above can understand. Overall, the enhanced method has an advantage in improving project performance and influence increased productivity.

3.2. Background
3.2.1. Earned Value Management (EVM)

EVM is a project management approach that incorporates schedule, costs, and scope to measure project performance [11-14, 16, 17, 60, 62]. Based on planned and actual values, EVM helps construction project managers predict and analyze a project’s health to adjust accordingly [11-15, 17]. The EVM method used currently is through Earned Value Management Systems
(EVMS). The organizations that use EVMS use it through purchased software packages, internal work processes, spreadsheet tools, and EVM templates.

EVM’s basic concepts date back as early as the 1890s [14]. Industrial engineers used a similar method to account for cost and production [14]. The EVM model became a vital method to program management in 1962 by the U.S. Navy [14, 59]. In 1966, the United States Air Force directed the use of earned value, also known as the USAF EVMS, combined with other planning and monitoring fiscal requirements for Air Force programs [14, 59, 60]. The prerequisite was entitled, the Cost and Schedule Planning Control Specification (C/SPCS) [14, 59, 60]. Over the decades since the development, the concept and its principles have remained unchanged. Since the inception of the U.S. Air Force earned value concept, it has evolved over the years, improving its viability to the U.S. Government and private industry. The EVM method since its conception remained basic and unchanged for many years. Many industries, including production, manufacturing, research, development, and even construction employ some form of EVM tailored to suit their performance objectives. However, a lack of employment of all functions of EVM can lead to a false sense of security in the performance of a project. Countries like the United States, Europe, England, Canada, Australia, Japan, Russia, and China all use the EVM method [59].

In the 1960s, the U.S. Government drafted 35 criteria used with the U.S. government’s contractor management systems [59]. In the 1990s, the American National Standard Institute (ANSI) and the Electronic Industries Association (EIA) created these into 32 standards for EVMS, resulting in the ANSI/EIA 748 standard [59, 61]. For technology systems used in several U.S. government agencies such as the Department of Defense (DoD) and National Aeronautics and Space Administration (NASA), this has now come to be the gold standard [61]. The
ANSI/EIA 748 standard used in DoD uses traditional EVM principles but does not account for quality control cost and schedule impacts. The EVMS guidelines centered around cost and unit costs [61].

According to a detailed study by Fleming and Kopelman [21], once the project reached no more than 20% complete, the project performance indices could be used to foresee the outlook of the project with a plus or minus 10% deviation [21]. The capability of EVM at the time it became most popular could enhance the analytical and forecasting ability in improving the project progress. The EVM method was an impactful project management measurement tool available in the industry at that time [3-6, 21]. The core elements of project success are project cost, duration, quality, and safety [15]. The industrial construction industry accounts for cost and duration in the current EVM method, but no known formulae within the EVM process account for quality and safety [3, 21], which is demonstrated by reviewing the EVM terms and formulae discussed below. Some of the EVM metrics are used to represent both cost and schedule factors. Therefore, for clarity, variables are defined and denoted as either function of cost ($S$) or schedule duration ($t$).

- The budget at completion (BAC) is the total of all budgets for the project, expressed in terms of total cost $[BAC(S)]$ or man-hours $[BAC(t)]$ budgeted for the project. No formula exists for this.
- The cost EV $[EV(S)]$, also referred to as the Budgeted Cost of Work Performed (BCWP), is calculated by multiplying the exact percent complete by the BAC (Equation 1). This metric indicates the value of the work performed during the period [4-6, 21]. The schedule EV $[EV(t)]$ represents earned man-hours calculated using Equation 2.

$$EV(S) = \text{Actual \% Complete} \times BAC(S)$$  \hspace{1cm} (1) \\
$$EV(t) = \text{Actual \% Complete} \times BAC(t)$$  \hspace{1cm} (2)
• The cost PV $[PV($)\]$ , also referred to as the Budgeted Cost of Work Scheduled (BCWS), is calculated by baselining the accepted budget of the project between the owner and contractor (Equation 3). This metric represents the approved budget of the assigned scheduled work to be completed [4-6, 21]. The schedule PV $[PV(t)]$ is the approved budgeted man-hours agreed upon by the owner and contractor to complete the project (Equation 4). The plan values for cost and time are aligned in the schedule.

\[
PV($) = Accepted\ BAC($) \tag{3}
\]

\[
PV(t) = Accepted\ BAC(t) \tag{4}
\]

• The AC $[AC($)\]$ is always a function of cost and represents the cost expended during a specific period [4-6, 21]. AC is measured rather than calculated.

• The cost performance index (CPI; Equation 5) is a numeric index that represents project performance [4-6, 21], calculated as the ratio of cost EV $[EV($)\]$ to AC $[AC($)\]$. The CPI value may be greater than, equal to, or less than 1.0, indicating the project is under budget, on budget, or over budget, respectively.

\[
CPI = \frac{EV($)\}{AC($)\} \tag{5}
\]

• The schedule performance index (SPI; Equation 6) measures the schedule’s project performance [4-6, 21] as the ratio of schedule EV $[EV(t)]$ to PV $[PV(t)]$. The SPI value may be greater than, equal to, or less than 1.0, indicating the project is ahead of schedule, on schedule, or behind schedule, respectively.

\[
SPI = \frac{EV(t)}{PV(t)} \tag{6}
\]

• The cost variance (CV; Equation 7) is the difference between what should have been spent $[EV($)\]$ and what has been spent $[AC($)\]$ for the project period [4-6, 21]. The interpretation of CV varies; therefore, it is necessary to review other factors for use as a management metric. For
example, an underspent project period ($CV$ greater than 1.0) may indicate that the project is truly under budget if the underspending is due to completing more work with fewer resources. Otherwise, the construction project manager assesses if underspending is due to absenteeism, productivity factor, or uncompleted activities in the schedule. If it is determined the underspending is due to absenteeism, the construction project manager can conclude that the scheduled activities not completed must be rescheduled and could delay the project. The schedule’s impact for the delays has a high probability of increasing the cost and therefore the project manager would conclude that the project is not under budget. The planned, uncompleted activities must be finished before critical path activities requiring their completion or project completion.

\[ CV = EV(\$) - AC(\$) \] (7)

- The schedule variance ($SV(t)$; Equation 8) is the difference between earned schedule completion [$EV(t)$] and planned project schedule completion [$PV(t)$] [4-6, 21]. This simplified metric indicates if the project is ahead (greater than 1.0) or behind (less than 1.0) schedule for the period reported.

\[ SV(t) = EV(t) - PV(t) \] (8)

- The Estimate at Completion (EAC; Equation 9) is a forecasted value of the total cost of completing the planned work [4-6, 21]. It is calculated as the difference of the BAC(\$) and EV(\$) divided by the product of the CPI and SPI, with the addition of AC(\$). The EAC represents the AC to date plus the remaining value assuming no change in CPI and SPI. The value projected using the formula calculates the total cost at completion up to a point in time [4-6, 21]. The formula supports the significant outcome because the cost and schedule indices influence the remaining work to be completed for cost and schedule [6].
\[ EAC(\$) = AC(\$) + \frac{BAC(\$)-EV(\$)}{CPI \times SPI} \] (9)

- Estimate to Complete (ETC) is an estimation done in EVM to calculate the needed cost to complete the project (Equation 10). The ETC metric is an important metric used by construction project managers to forecast values for remaining work. The forecasted values could be cost or man-hours. In either case, the two values can be converted by using a composite rate from the baseline.

\[ ETC = EAC(\$) - AC(\$) \] (10)

- The Total Performance Index (TPI) value is the value of the CPI, and SPI added together and then divided by the total value that can be achieved [4-6, 21]. The formula (Equation 12) gauges the total performance of the project of the cost and schedule. This TPI does not include quality and safety.

\[ TPI = \frac{CPI + SPI}{2.0} \] (11)

3.2.2. Earned Value Analysis (EVA)

EVA is the fundamental analysis used in EVM [4, 6, 7]. EVA allows the project construction manager to measure the amount of work achieved on a project beyond the fundamental review of cost and schedule reports [4-6, 10, 21, 62, 63]. EVA provides a method that permits the project to be measured by the progress achieved [4-6, 21]. This is the application of strategic analysis of quantitative performance indexes to predict early indications of project performance. When used accurately, EVA provides the need for eventual corrective action [3-6, 9]. The project manager can then use the progress measured to forecast a project’s total cost and date of completion, based on trend analysis or application of the project [4-6]. This method relies on critical metrics such as PV, EV, AC, CPI, and SPI [2, 4, 6, 9, 10, 64]. For the EVA to be as accurate as possible, a detailed project plan must be created [4-7]. The project plan is a narrative
description of the project scope, objectives, assumptions and risk, constraints, and critical path deliverables [4-7]. The project plan provides a documented basis for making future project decisions and confirming or developing a shared understanding of project scope among the stakeholders [4-7]. A WBS is a straightforward interpretation of the project’s work scope, documenting the order and description of the tasks performed and their relationship to the project deliverables [5, 6, 10]. The WBS breaks down all authorized work scope into appropriate organized plan that can be followed day by day [5, 6, 10]. The WBS must expand to the degree necessary for management action and control based on the intricacy of the work [5, 6, 10]. One of the prerequisites to project success is extensive project planning [5, 6, 10]. The more detailed and fluid the plan, the more accurate the reporting be. The more precise the reporting, the higher level of confidence stakeholders have in completing EVA. Accurate reporting also supports the construction project manager in making corrective action decisions [1, 2, 57, 63, 65].

3.3. Methodology

The improved methodology has two contributions to enhance the value of a more accurate total performance index incorporating quality control. The first part uses standard EVM formulas but with improved formulas by incorporating the QSPI to calculate a more defined and realistic total construction performance index. The second part is conducting analysis utilizing descriptive statistics using JMP software (statistical software package). The analysis reviews the mean, standard deviation, upper and lower confidence intervals. The descriptive statistics compare EVM metrics of furnaces without a quality control index. The results and discussion section produce the results using the quality control index of 0.90 and 0.85. The contribution demonstrates the significance and value of incorporating a quality control index to support the project’s overall outcome.
The Earned Value Construction Method (EVCM) uses prescriptive formulas to calculate indices and variances. In construction, most managers are familiar with the basic concepts of EVM. The construction project manager uses two indices and the variances for evaluating project performance. The first index is the Cost Performance Index (CPI), which is needed to monitor the project’s cost [58]. The second index is the Schedule Performance Index (SPI) that monitors the schedule’s health [58]. The use of cost and schedule variances to determine if trends are occurring [19].

The project must have project data inputs to calculate the performance indices. The data inputs are the project deliverables converted into a value. The values are numeric in representing time, quantities, or actual measurements. This value is known as the planned value (PV) [58]. The PV derives from the construction scope of work or scope criteria. For example, a project’s planned value is installing a three-inch diameter pipe of 500 linear feet or 1,000 man-hours. The scope is then put into a hierarchical arrangement known as a work breakdown structure (WBS). The WBS is a step-by-step, in order of duration, of all planned project deliverables. These project deliverables in the schedule are start-start (SS) or start-finish (SF) activities. The SS activities are project deliverables that can start at the same time. The SF activities are those project deliverables that must start and finish before the next deliverable can begin.

The indices have two known outputs, CPI and SPI, which are interpreted in equal to, greater than, and less than 1.0. If the result is greater than or equal to 1.0, the project executes as planned or better. When the result is less than 1.0, there is a reason to believe that the project’s health is impacted. The project construction manager assumes the risk and accepts responsibility for its adverse performance [3-7, 21].
3.3.1. Quality Management Plan (QMP)

It is an industry practice for construction companies to have a corporate Quality Management Plan (QMP) [66]. The QMP outlines the policies, procedures, and processes of employing quality control (QC) and quality assurance (QA), which are summarized in Table 3.1 [16, 18, 19, 66]. Quality Control and QA are considerably different in definition but complement one another in a good QMP [66]. Without these, the project can end up with inspection gaps, construction issues, materials defects, and non-compliance to specifications and drawings.

Within the QMP is a quality assurance and surveillance plan (QASP). The QASP outlines the percentage of work and construction disciplines to be observed for compliance. The QASP supports QC inspections by reducing the number of findings and non-compliance construction issues. The QASP influences the requirement for quality data and reporting necessary for quality process management [66].

Table 3.1. Elements of a Quality Control Plan

<table>
<thead>
<tr>
<th>QC Plan Elements</th>
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</thead>
<tbody>
<tr>
<td>Organizational Chart</td>
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<tr>
<td>Project QC Personnel</td>
</tr>
<tr>
<td>Personnel Qualifications and Certifications</td>
</tr>
<tr>
<td>Project Quality Communications Plan</td>
</tr>
<tr>
<td>Quality Training</td>
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<tr>
<td>Work Task Quality Inspections</td>
</tr>
<tr>
<td>Inspection and Test Plan (ITP)</td>
</tr>
<tr>
<td>Subcontractor and Third-Party QC Plan</td>
</tr>
<tr>
<td>Identified Project Quality technical specifications</td>
</tr>
<tr>
<td>QC of Materials and Equipment</td>
</tr>
<tr>
<td>Project Quality Records and Documentation</td>
</tr>
<tr>
<td>Quality Assurance and Surveillance Plan (QASP)</td>
</tr>
</tbody>
</table>

Also, within the QMP is the procedure and requirements of the ITP. The ITP, when executed as planned, requires the contractor to show in good faith how they plan to install materials and equipment and perform inspections per the specification admit openly and in
writing that they have done something wrong. The issues of quality management addressed in this study are supported by Bakke et al., [67]. They found that projects with cost overruns are due to inadequate quality-project mandates with an unclear scope, design, and reporting objectives [67]. Overall, quality management practices and performance lead directly and indirectly to improved quality performance [66]. The advantages and synergistic reporting with current EVM methods improve construction waste reduction and re-work cost in industrial construction [68].

3.3.2. Inspection and Testing Plan (ITP)

An Inspection Test Plan (ITP) is a frequently required document submitted by the contractor and their construction quality control plan. The ITP for industrial projects is reviewed by the owner’s construction and quality team. However, the reporting of impacts due to quality issues is not captured in a consolidated report. The inspections and tests that the contractor performs are also not outlined in a schedule. The ITP reporting is done unilaterally in a separate and single report. Thus, quality reports are independent of EVM performance reporting.

The contractor advises the client on inspection and test activities to support the quality control plan. The ITP also acts as a checklist to perform the inspections outlined in the ITP. The adherence of the ITP also generates a report to the owner of the compliance, findings, or non-conformance results. The contractor and their subcontractors must record the results of the prescribed inspections and tests performed during the project. The ITP also influences the crafts to execute construction activities following industry practices and specifications. The ITP is one of the many plans vital to the success of the project.

When a Non-Conformance Report (NCR) is published, the contractor must engage in the acceptance and provide a disposition that provides the value of the cost of re-work, replacement,
project delay, and schedule adjustments recorded in the NCR response. However, the schedule and EVM reporting metrics do not provide these impacts of additional re-work and construction costs. The documenting of the non-conformance serves to record the problematic areas from beginning to end and helps in prescribing corrective measures to prevent the reoccurrence of these problems in the future. The historical data is used to reduce future projects’ costs by documenting non-conformance during the project. Again, in this ITP process, there are no prescribed processes to measure the performance of these inspections and testing. ITP activities are not incorporated in the schedule for valuation.

While both Construction Quality Control Plans and Inspection and Test Plans are intended to control construction quality, your construction QC plan focuses on a wide range of elements. Quality Control Plan for construction outlines how the quality of construction activities be managed during the project. The Quality Control Plan also helps establish a framework with defined procedures and practices to ensure that the client’s completed construction activities meet or exceed the project’s specified quality requirements.

In comparison, the inspection and test plan (ITP) only focuses on inspections and tests as a method of quality control. They incorporate an inspection and test plan to catch defects or non-conformances before they become costly and impactful to the project. For example, if the contractor fabricates steel components, the ITP may well include inspecting inbound materials and performing X-Ray weld inspections to ensure welds comply with specifications. The inspection and test plan is essential to good quality control during the execution of construction projects. In construction, every purchased material and phase of work should be inspected for compliance with the specifications and engineered drawings. The process flow of integrating ITP
and EVCM is provided in Figure 3.1. The improvement that is not evident in traditional methods of EVM is the adding of ITP activities in the schedule that is progressed.

Figure 3.1. ITP Cycle Incorporating EVCM

3.3.3. Earned Value Construction Management (EVCM)

The improved method of ECVM incorporates a new performance index derived from quality control performance. Hassan et al. [69] concluded that the construction industry requires further improvement and development concerning quality [69]. There is always a requirement to improve and enhance the quality of industrial construction [23]. In quality control, the construction industry has three main areas contributing to low quality: lack of management commitment, not understanding or ignoring the quality specifications, and poor craftsmanship due to lack of inspection plan [23]. Other quality issues contributing to construction project impacts were instituting an approved quality control plan, measuring quality performance as being too complicated, and planning to incorporate quality activities [23]. Quality improvements to schedule and cost have grown in attention among the construction industry professionals [23, 69]. The desire to complete construction projects within the approved budget and duration using
quality control principles has equal importance to project controls, fiscal responsibility, and safety [23, 69].

The EVCM method now incorporates quality in the project management process. There is an inclusion of new terms, equations, and results to analyze the project. The process is outlined in Figure 3.1. In most construction projects, the construction project manager wants to know CPI and SPI. As previously mentioned, CPI is tied to cost while SPI is tied to a schedule. The new earned value performance index, QSPI, measures the quality control plan’s performance and the ITP. The quality control inspection and testing activities are added to the schedule to progress and calculate the QSPI. The examples of quality control activities in industrial construction schedules would come from the QCP and ITP that are referenced in Table 3.1. The EVCM process now uses CPI, SPI, and QSPI to then calculate the total performance index of the project’s overall health.

- Construction Budget at Completion (CBAC) is the total approved budget ($) approved by the owner.
- Construction Man-Hours at Completion (CMAC) is the total approved man-hours (t) authorized approved by the owner and agreed by the contractor. The owner and contractor must agree on the approved man-hours, or the indices will not be valid.
- Construction Planned Value (CPV) is the total planned man-hours and quantities installed aligned to the construction activities required to complete the project.
- Construction Actual Value (CAV) is the total man-hours, cost, and quantities installed at time of the reporting period. All three-reporting metrics must be collected and reported separately.
- Construction Earned Value (CEV) is calculated using Equation 12 and 13.

\[
CEV(\$) = \% \text{ Completed} \times CBAC(\$) \tag{12}
\]
\[ CEV(t) = \% Completed \times CMAC(t) \]  

- Quality and Safety Planned Value (QSPV) is calculated using Equation 14. This value represents the total planned man-hours approved to support the project.

\[ QSPV = QSI(t)_{Planned} \]  

- Quality and Safety Earned Value (QSEV) is calculated using Equation 15.

\[ QSEV = \% QC and Safety Completed \times QSPV \]  

- Quality and Safety Actual Value (QSAV) is calculated using Equation 16. This value represents the total man-hours expended for quality and safety inspections.

\[ QSAV = QSI(t)_{Expended} \]  

- Quality and Safety Performance Index (QSPI) is the measured performance index for all quality control and safety inspections. The quality control activities are derived from the project’s Inspection and Testing Plan. The safety inspections come from the agreed safety audit plan to reduce risk and injury.

\[ QSPI = \frac{QSAV}{QSPV} \]  

- Total Construction Performance Index (TCPI) is calculated by adding all the indices and dividing by 3.0. Each performance indices are weighed equally as they have equal impact to a project.

\[ TCONPI = \frac{CPI + SPI + QSPI}{3.0} \]  

The side-by-side comparison in Table 3.2 shows the added new terms supporting EVCM. The traditional method tends to use budget as means of gauging the health of the project. The cost of the project that is spent per the plan indicates that the project if spent per plan is progressing correctly. This method of analysis provides a sense of false assurance the project is on track. The EVCM method, however, uses the planned man-hours and cost conjointly that are
needed to support the project. The project man-hours that are validated by the project team in the schedule will coincide with actual productivity per the plan. The weekly plan versus spent provides the productivity factor metric for analysis against the plan. Under more complex projects where multi-craft integration is required the EVCM method will provide the details not supported by the traditional method. In Table 3.2, the integration of construction, quality, and safety are evident to support the EVCM. The new formulas and definitions are provided with a demonstration in the use of EVCM. In the schedule example provided in Appendix A, the outline of quality and safety activities is provided for reference. The outcome and desire for all construction project managers is to efficiently certify the schedule through multiple reviews. It is essential for the approved schedule to be validated and approved by the project team which includes field craft subject matter experts. The approved schedule that is to be accurately progressed must have sufficient details and activities to support the EVCM metrics.

The industrial construction industry traditionally uses two types of contract methods. The two types of contract methods are time and materials (T&M) and lump sum (LS) contracts. In both contract methods, the owner is paying for a budgeted number of man-hours to complete the construction project. When there is a change order, the contractor submits an estimate of additional man-hours and materials needed to perform the added activity. The EVCM method adds the Construction Man-Hour at Completion (CMAC) to understand during the planning and schedule creation of how many man-hours are budgeted for the project by each contractor regardless of the contracting method used. The CMAC can be used to calculate a direct and indirect labor rate charged to the owner.

Like the traditional EVM of PV and EV, the improved method incorporates Construction PV (CPV) and EV (CEV). In the EVCM method, the PV and EV are applicable to cost only. The
CPV and CEV in the EVCM method apply to construction man-hours for each planned activity. The importance of CPV and CEV is to keep the values of cost and schedule separate. In the construction management of the project, it is essential to evaluate cost and schedule. In the industrial construction environment, there are traditional construction projects, maintenance, and repair, and turnarounds. The turnarounds are critical, complex, cost, and schedule-driven.

Table 3.2. EVM Comparison to EVCM Method

<table>
<thead>
<tr>
<th>EVM Basic Method</th>
<th>EVCM Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget at Completion (BAC)</td>
<td>Construction Budget at Completion (CBAC)</td>
</tr>
<tr>
<td>Earned Value (EV)</td>
<td>Construction Man-Hours at Completion (CMAC)</td>
</tr>
<tr>
<td>Planned Value (PV)</td>
<td>Construction Planned Value (CPV)</td>
</tr>
<tr>
<td>Actual Cost (AC)</td>
<td>Construction Actual Value (CAV)</td>
</tr>
<tr>
<td>Cost Performance Index (CPI)</td>
<td>Construction Earned Value (CEV)</td>
</tr>
<tr>
<td>Schedule Performance Index (SPI)</td>
<td>Quality and Safety Planned Value (QSPV)</td>
</tr>
<tr>
<td>Cost Variance (CV)</td>
<td>Quality and Safety Actual Value (QSAV)</td>
</tr>
<tr>
<td>Schedule Variance (SV)</td>
<td>Quality and Safety Earned Value (QSEV)</td>
</tr>
<tr>
<td>Estimate at Completion (EAC)</td>
<td>Quality and Safety Performance Index (QSPI)</td>
</tr>
<tr>
<td>Estimate to Complete (ETC)</td>
<td>Total Construction Performance Index (TCPI)</td>
</tr>
</tbody>
</table>

In many cases, turnarounds are short-term with numerous construction and maintenance activities. Short-term projects like turnarounds, most contractors cannot invoice every week for accurate cost reporting. The contractors can forecast, but the vendor and subcontractor cost reporting proves to be a challenge. The EVCM method supports the ability to be pertinent in any construction environment. The EVCM method allows for reporting and analyzing cost, schedule, and quality.

The EVCM method, when applied, generates a new Total Construction Performance Index (TCONPI) provided in Equation 18. The project controls scheduler generates CPI, SPI, and QSPI. For example, the CPI is 0.96, SPI is 0.96, and QSPI is 0.88. Following the Equation
18, the TCONPI is 0.93. Using the traditional EVM method, the initial conclusion would have
the total performance index of 0.96, respectively. However, with the EVCM method and using a
QSPI to calculate the TCONPI, the new analysis concludes that the variance is 0.03 less than
TPI. If the acceptable variance is 0.05, then under the EVM method, the project is within
tolerance but not within tolerance in the EVCM method. The EVCM method would trigger a
required root cause investigation into the impacts. The root cause investigation would point to
the QSPI, identifying that our quality control during construction needs improvement. If no
improvements can be made, then the downward trend continues intensifying schedule and
project cost impacts.

3.3.3.1 EVCM Demonstrative Example

Utilizing Table 3.2 and previously presented formulas, a step-by-step demonstration
shows the functionality and use of the EVCM method. To fully demonstrate the application of
EVCM, a construction project scenario is presented. Project A has a CBAC of $190,000 with a
CMAC of 2,000 man-hours installing 2,000 linear feet of pipe, valves, and instruments. The
contractor has ten pipefitters resourced to the project working five days a week at ten hours per
day. The project is a four-weeks in duration. The period reporting has the project reporting 75%
complete with the CPI being .95 and SPI being .95, thus the TPI is also .95 per the EVM method.
With this information the following data is presented using EVCM method:

1) CBAC is $190,000.

2) CMAC is 2,000 man-hours with installing 2,00 linear feet of pipe. Of the 2,000 man-hours
budgeted only 1,500 man-hours are used for installation, while 500 man-hours are used for
quality and safety activities.
3) CPV of this project is equated to the crew of ten pipefitters spending 100hrs a day and 500hrs per week. The simple analytics of productivity shows that the crew must install 500 linear feet per week to meet the schedule and budget.

4) CAV for this project is 1,125 man-hours spent and 1,425 linear feet of pipe installed. The current spend is $142,500. The importance of CAV is to validate your SPI and CPI. If the CAV values coincide with SPI and CPI then the construction project manager know the progress reporting is accurate. If the values do not align then a root cause analysis needs to be administered as the project may be in jeopardy of having inaccurate reporting.

5) CEV for this project based on the information provided is 75% complete times 2,000 which equates to 1,500 man-hours spent and installed pipe.

6) QSPV is the man-hours planned to support the quality and safety activities for the project. For this project 500 man-hours are planned.

7) QSAV for this project is 375 man-hours.

8) QSEV for this project is 325 man-hours.

9) QSPI for this project is 375 divided by 325 equates to an index of .87.

10) TCONPI is the final step in this process to calculate a more realistic and valid performance index of the project. Now that QSPI is calculated and have validated CPI and SPI with the CAV, the TCONPI can be calculated. CPI of .95, SPI of .95, and QSPI of .87 are added together and then divided by 3.0. The TCONPI for the project is now .92. The TCONPI is .03 less than the TPI using the traditional method of EVM.

3.3.4. Quality and Safety Performance Index (QSPI)

The schedules produced today for construction are of direct man-hours or quantities of installed materials and equipment. The schedules are absent of indirect man-hours such as
supervision, quality control inspections, and safety audits. The absence of not having the
progress of quality control inspection performance can impact the schedule and cost of a project.
Published articles include a quality assessment system, quality variance, and quality performance
index [17, 18]. However, these articles present a methodology for earned value specific to
agriculture and statistical approaches for civil engineering [18, 19]. The integration of EVM and
quality in these articles does not present an index of quality performance during actual industrial
construction. The articles also do not provide a specific quality performance index that identifies
the non-conformance of construction activities that impact cost and schedule. The results of
quality control inspections in industrial construction are independent of the schedule and
recorded separately. Without the integration of quality and safety activities that are impactful to
schedule and cost, this poses an adverse result to the project’s performance.

The EVCM integrates quality performance with cost and schedule in one central location.
There is a tremendous advantage in a more uniform reporting process from a single source that
currently derives the indices needed to analyze the project performance. The study discusses and
applies earned value and schedule performance management in establishing an index for quality.
The quality and safety performance index be a standalone performance index using the quality
and safety planned, actual, and earned value method within the schedule. The new quality and
safety performance index introduced is to be incorporated into calculating the Total Construction
Performance Index.

The execution of industrial construction projects, especially an Architectural,
Engineering, and Construction (AEC) project, involves a larger budget and long duration. Yet,
there is no single tool to capture and monitor quality performance with both duration and cost
[17, 19]. In schedules, these industrial construction projects normally do not include indirect
man-hours of quality inspections and testing. These schedules include only those direct man-
hours of activities that can produce productivity. The problem statement within industrial
construction is that there is no inclusive capture of any performance impacts related to cost and
schedule for quality control activities [17-19].

For example, there are two activities, and the first activity is to weld two ten-foot in
length and 6-inch diameter pipes together that have flanges on each end. The second activity is
the bolting of the flanges to the tie points using torque specifications. Under EVCM, all
construction activities aligned to quality control and ITPs are detailed in the schedule. During the
inspection, the inspector finds that the weld is not complete, and two bolts do not meet the torque
specification. The original activity was welded on the ground and lifted into the pipe rack. The
crew now must unbolt and re-rig the pipe back up to be removed and placed on the ground for
re-work. All this re-work has an additional cost and added man-hours, which has an impact on
the schedule.

By adding activities such as hold points for inspections, weld inspections, and releases
upon satisfactory compliance through quality inspections to the schedule, the project avoids
these unnecessary costs and schedules. Traditionally these additional costs and schedule impacts
are not captured in the schedule under the EVM methodology. Thus, skewing the true progress
of the project. Throughout the project, no formal quality performance index tells stakeholders
and managers their quality plan supports the project and is truly on schedule and within budget
[18, 19].

The Quality and Safety Planned Value (QSPV) represents the number of planned quality
inspections that support the period’s construction activities (Equation 14). The actual time spent
in man-hours to perform quality and safety inspections is the Quality and Safety Actual Value
(QSAV) (Equation 16). The Quality and Safety Earned Value (QSEV) is derived using Equation 19. The QSEV can be calculated daily or weekly. For example, the construction project planned on four CWI inspections for four welds at three man-hours for a two-person inspection team and only completed three inspections. The QSPV for the day is 12 man-hours. However, the QSAV for the day is nine man-hours with 75% completion.

Using Equation 15 in this example, the QSEV is nine man-hours would be the result.

Using the QSPI formula, Equation 17, the output would be QSPI = 9/12, resulting in an index of 0.75. With the index being less than 1.0, the conclusion supports there is an issue with the quality inspections and does not meet the schedule’s plan. This requires an in-depth look as to why. The analysis of this also concludes there are impacts on cost and planned activities relying on releases’ from completed inspections.

Until these releases are complete, the next activity cannot begin. The impact of these activities, which are not allowed to begin as planned, creates a domino effect on the schedule. These impacts to the schedule then also create a cost burden that, if not captured, are unknown until the project is nearly complete. The proposed solution is to capture the quality control inspections in a separate WBS group within the schedule. The activities to support the ITP be planned and the man-hours are captured to support the inspections. The method shows through the QSPI when inspection hours are increasing due to re-inspections. This potentially points to poor work processes and craftsmanship.

3.4. Furnace Data Case Study

The case study presented in this study demonstrates the EVA technique for four furnaces’ weekly construction performance. The four furnaces included in this case study, (e.g., Furnace A, Furnace B, Furnace C, and Furnace D) are equal in size and use the same contractors. The
furnaces were completed in 2019. The furnace’s scopes of work and budgets are also equal. Each furnace’s general scope of work includes civil, mechanical, pipe and valve install, instrument, and electrical cabling. Furnaces in industrial plants are an intricate and vital piece of equipment in industrial processes [70, 71]. Organizations in the industrial sector must take full advantage of supply and demand by improving the maintenance, repair, and modernization of furnaces with improved technologies [72]. The market demand requires that the furnaces operate at full capacity and not trip by shutting down due to safety automation [70]. The rise in energy costs influences heat recovery by employing new technologies and design [70, 71, 73].

The furnace data presented in Table 3.3 represents the mean weekly construction performance for each performance index. To comply with proprietary data restrictions, the work scope for all the furnaces in this case study is equal, and the contractors performing the work are the same. To apply the basics of EVA, the furnace data in Table 3.4 in this case study centers around the basic methods of EVM. There are many earned value software packages that automatically calculate these indices [74]. Most construction organizations utilize Primavera 6 or MS Project, which provides the EVM indices. However, depending on the scheduler’s experience level and understanding of EVM calculations continues to be a problem in using EVM [3, 7, 18, 21]. In industrial construction, the lead scheduler must be well versed in EVM.

Certain elements of the project, such as soil compaction, concrete strength, welding of pipe and flanges, installation of valves, torque bolting, I/O testing of terminations and instruments, and pipe pressure testing, are traditionally checked or tested by third-party testing and inspection organizations. These prescribed tests are conducted before and during the construction project. The quality of other project elements is examined by the project engineer and design team, or one of the owner’s quality managers.
Table 3.3. Weekly Mean Industrial Furnace Performance Data

<table>
<thead>
<tr>
<th>WEEK</th>
<th>FURNACE</th>
<th>CPI</th>
<th>SPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>0.96</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>1.20</td>
<td>1.11</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>0.86</td>
<td>0.99</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>0.96</td>
<td>0.98</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>1.02</td>
<td>0.99</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>0.97</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>0.98</td>
<td>0.95</td>
</tr>
<tr>
<td>1</td>
<td>C</td>
<td>1.01</td>
<td>0.99</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>0.96</td>
<td>0.95</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>1.10</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>1</td>
<td>D</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>2</td>
<td>D</td>
<td>0.99</td>
<td>1.10</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>0.93</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Figure 3.2. Weekly CPI Performance Bar Chart for Industrial Furnaces
Figure 3.3. Weekly SPI Performance Bar Chart for Industrial Furnaces

Figure 3.4. CPI vs. SPI with Linear Trend Line

Note: The solid black line represents the actual SPI progress. The solid grey line represents the actual CPI progress. The dashed black line represents the SPI linear trend line.

The following descriptive statistical data shown in Tables 3.6 and 3.7 supports the misconception of the project is within cost and schedule using the EVM method. The evaluation of the trend lines in Figures 3.2 thru 3.4 indicates that there are needed analysis between CPI and
SPI. However, applying EVCM to truly use EVA principles for industrial construction activities would be beneficial. If the project, during construction, encounters quality issues the impacts are not known till the end when course correction is too late. This is resolved by incorporating quality control activities into the schedule and calculating the QSPI.

The case study Table 3.4 shows that under the EVM method the project for Furnace A through D had a mean CPI of 0.99. This indicates that the budget and cost for the four furnaces met the expectations with a variance of 0.01 over budget. The mean SPI in Table 3.5 for the four furnaces was 1.0, meaning all four furnaces met their planned schedule precisely. The EV analysis under the traditional EVM principles would conclude that the four furnaces completed with praising success. However, when the comparison is done against Tables 3.6 and 3.7 using EVCM, the outcome is not as favorable. More analysis of this outcome is provided in the results and discussion section of this chapter.

Table 3.4. CPI Descriptive Statistics Furnaces A-D

<table>
<thead>
<tr>
<th>Furnace</th>
<th>CPI</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Upper CI</th>
<th>Lower CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.99</td>
<td>0.99</td>
<td>1.2239</td>
<td>0.7611</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.98</td>
<td>0.98</td>
<td>1.0243</td>
<td>0.9406</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1.01</td>
<td>1.01</td>
<td>1.1109</td>
<td>0.9141</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>0.96</td>
<td>0.96</td>
<td>1.0000</td>
<td>0.9189</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>0.99</td>
<td>0.99</td>
<td>1.09</td>
<td>0.88</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.5. SPI Descriptive Statistics Furnaces A-D

<table>
<thead>
<tr>
<th>Furnace</th>
<th>SPI</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Upper CI</th>
<th>Lower CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.02</td>
<td>1.02</td>
<td>1.1163</td>
<td>0.9226</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.98</td>
<td>0.98</td>
<td>1.0143</td>
<td>0.9456</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.98</td>
<td>0.98</td>
<td>1.0177</td>
<td>0.9472</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>1.01</td>
<td>1.01</td>
<td>1.1089</td>
<td>0.9111</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>1.00</td>
<td>1.00</td>
<td>1.06</td>
<td>0.93</td>
<td></td>
</tr>
</tbody>
</table>
3.5. Results and Discussion

The issue is that the quality control process does not include capturing the inspections or the re-work because of the non-conformance in the schedule. The non-conformance of these inspections requires re-work. The re-work then equates to man-hours from existing resources and equipment that are needed on remaining activities. These resources and man-hours needed for the re-work impact the schedule and cost of the project. For example, a crew of twenty personnel engaged in daily construction activities planned for six weeks working ten hours a day and five days a week equates to 6,000 man-hours. According to the CPI and SPI of direct activities, the project is at 0.98 respectively for both.

However, the welding activity of two sections of pipe failed the X-Ray inspection and must be redone. The activity requires an additional five-hour duration for eight of the twenty personnel. The re-work is forty hours not accounted for in the schedule or tracked in the CPI and SPI reporting. This project’s composite rate is $95 per man-hour, equating to an additional labor cost of $3,800, not accounting for additional materials. For a project that has twenty-five field welds and fails 4, the cost could be at a minimum of $15,200. The project value is $175,000 making the additional labor cost an added 8.67% to the project. The welding success at this point has a success rate of 93.75% but a failure rate of 3.75%.

The schedule impact is resource loss of two welders, two welder helpers, two fire watches, and two sniffers for unplanned re-work. Another impact to the schedule is adjusting already planned work activities that are not accomplished due to the re-work. The schedule eventually must push out for a whole day without any indication as to why. The reason is known but not captured in the schedule. The final performance on the quality of the project is reviewed close to completion, or the startup process. The designer, construction team, operations, and
owner issues a punch list of items that need to be corrected for the project. This final inspection and acceptance by the owner certify that the construction project meets the quality expectation set forth by the project documents.

Once all the final inspections and owner acceptance are done, the final closeout is invoicing, Commissioning and Start-Up, and project closeout. It is during this phase of the project that the contractor and owner learn that the reporting indicated in Table 3.4 and 3.5 are not as accurate as reported. In Table 3.6, the simulated QSPI is 0.90 for all furnaces. Using EVCM to calculate the TCONPI, the result is 0.96 for all furnaces. This is a negative variance of 0.04. This is not grossly alarming but does have an impact on the construction project manager who now after reporting a 0.99 must ask for more funding to close out the project. In addition to asking for more money, the construction project manager is now requested to identify where the shortfall is. This information would be very difficult to provide and account for additional staff hours doing a root cause investigation.

In Table 3.7, the simulated QSPI is 0.85 for all furnaces. Using the traditional EVM method would result in substantial inflated reporting. By applying the EVCM, the project manager would see that all furnaces are at the thresh hold of needing to investigate the impacts of the projects. The thresh hold being 0.95 overall. The EVCM would point to the specific area of concern needing improvement. The QSPI would also influence the needing of addressing the schedule implications and additional costs to get back on schedule. The EVCM versus EVM in both simulated scenarios identifies an impact that could be improved early in the project.
Table 3.6. EVM versus EVCM with 0.90 QSPI

<table>
<thead>
<tr>
<th>Furnace</th>
<th>Mean CPI</th>
<th>Mean SPI</th>
<th>TPI</th>
<th>QSPI 0.90</th>
<th>TCONPI</th>
<th>Variance (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.99</td>
<td>1.02</td>
<td>1.01</td>
<td>0.90</td>
<td>0.97</td>
<td>0.04</td>
</tr>
<tr>
<td>B</td>
<td>0.98</td>
<td>0.98</td>
<td>0.98</td>
<td>0.90</td>
<td>0.95</td>
<td>0.03</td>
</tr>
<tr>
<td>C</td>
<td>1.01</td>
<td>0.98</td>
<td>1</td>
<td>0.90</td>
<td>0.96</td>
<td>0.03</td>
</tr>
<tr>
<td>D</td>
<td>0.96</td>
<td>1.01</td>
<td>0.99</td>
<td>0.90</td>
<td>0.96</td>
<td>0.03</td>
</tr>
<tr>
<td>Overall</td>
<td>0.99</td>
<td>1</td>
<td>0.99</td>
<td>0.90</td>
<td>0.96</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 3.7. EVM versus EVCM with 0.85 QSPI

<table>
<thead>
<tr>
<th>Furnace</th>
<th>Mean CPI</th>
<th>Mean SPI</th>
<th>TPI</th>
<th>QSPI 0.85</th>
<th>TCONPI</th>
<th>Variance (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.99</td>
<td>1.02</td>
<td>1.01</td>
<td>0.85</td>
<td>0.95</td>
<td>0.05</td>
</tr>
<tr>
<td>B</td>
<td>0.98</td>
<td>0.98</td>
<td>0.98</td>
<td>0.85</td>
<td>0.94</td>
<td>0.04</td>
</tr>
<tr>
<td>C</td>
<td>1.01</td>
<td>0.98</td>
<td>1</td>
<td>0.85</td>
<td>0.95</td>
<td>0.05</td>
</tr>
<tr>
<td>D</td>
<td>0.96</td>
<td>1.01</td>
<td>0.99</td>
<td>0.85</td>
<td>0.94</td>
<td>0.05</td>
</tr>
<tr>
<td>Total</td>
<td>0.99</td>
<td>1</td>
<td>0.99</td>
<td>0.85</td>
<td>0.94</td>
<td>0.05</td>
</tr>
</tbody>
</table>

3.6. Conclusion

In conclusion, EVM is used to analyze the project performance, calculate the variance for schedule and cost, and indicate the project health compared to the estimates [3, 7, 18, 21]. EVM is a critical technique for measuring project performance [1, 8, 21, 62]. EVM’s potential reasons for promising outcomes include improved work efficiencies, fewer re-work required, limited field change orders, reduced engineer errors and omissions, and work scope not as complex as previously understood [4, 6]. However, if not applied effectively or at all, you can expect cost overruns, scope creeps, push and pull management decisions with limited data, increased costs, and late schedule completion [62].

A quality control plan influences the control of the quality of labor, equipment, and suppliers. The quality control plan also controls work procedures to improve quality throughout the whole construction process, i.e., not just after the material is delivered or the phase of work completed. When the project adequately manages all critical elements of the construction process

57
to include quality, the outcome has a high probability of a successful project. Evidently, with the enhanced controls and including the quality control activities in the schedule that are part of a complete quality control plan, the project has fewer problems to fix and higher quality levels from start to finish.

In the EVCM method, the ability to help control costs by including quality control inspections that are non-conformance, which increases the project’s cost due to re-work. These additional costs need to be captured to assess the true cost of a project accurately. The improved method could potentially be used to capture the quality performance of subcontractors and third-party inspections. The additional costs associated to re-work due to quality are not captured in the traditional means of EVM. The conclusion by construction project managers is to question the true validity of the CPI. The knowledge of how accurate the CPI is at the end of a project that does not capture quality issues and re-work should be concerning to stakeholders and owners. If knowing the CPI is not accurate then the probability of the SPI not being accurate can be questioned. There are opportunities in some construction projects to accumulate fifteen percent savings by reducing engineering errors and reduce the amount of re-work due to inefficient quality [75].

The EVCM process captures all the quality control activities in the schedule. The improved EVCM incorporates the CPV, CEV, and CMAC for construction and QPV, QAV, QEV, and QPCI for all quality control activities. Using the CPV, CAV, and CEV, the project could progress daily or weekly and generate a new index. The added reporting performance index is QSPI, which now under the EVCM method has a value reported on quality progress. The EVCM, when applied, now has integrated quality into the schedule performance management. Quality is now on an equal playing field in EVM with its index that calculates in
the TCPI. The problem statement of capturing and reporting quality issues in a project is now answered in the EVCM method. The importance of a successful project is cost, duration, quality, and safety. EVM captures and reports on cost and duration. The improved EVCM method introduced depicts all components of a project to genuinely calculate and report the success by incorporating quality, a missing critical aspect of construction reporting. A construction quality control plan includes an inspection and test plan, but this should go beyond inspecting. The problem statement of how to collectively capture, track, and report under one reporting mechanism is ultimately desired. The EVCM method satisfies this desire and provides an added tool for construction project managers in industrial construction.
Chapter 4. EVCM Application Before and During a Pandemic

4.1. Introduction

The purpose of this chapter is to demonstrate the improvements of applying an improved Earned Value method. The improved method is Earned Value Construction Management (EVCM). The improved method integrates quality control activities into a schedule. The first objective is to compare industrial furnace construction data before and during the COVID-19 pandemic. The second objective is to report the significance of applying EVCM with the quality activities such as inspections and acceptance sampling for fabricated materials. The use of statistical quality control in project management is as important as using CPI and SPI to report the health of the project. In every aspect of construction project management regardless of industry, the overall objective is to provide a quality and safe project within budget and on time.

The use of statistical analysis to support or reject the hypothesis that the mean values of the Total Performance Index is equal to the Total Construction Performance Index, or they are not equal. The same method in chapter two is applied for the CPI and SPI. The difference in this chapter is the incorporating of COVID-19 policy and safety practices. The question being explored is if COVID-19 safety practices have an impact on productivity and cost. The inference in this chapter is that there is no impact as EVM practices do not capture the costs and impacts of quality and safety. The alternative inference is that EVCM during a pandemic is the best method to capture quality and safety impacts. The overall drawn conclusion is that EVCM should be applied in any construction environment. In addition to demonstrating the application of EVCM, we also introduce the three critical roles in addition to the scheduler to support the Front-End-Loading (FEL) of a project to ensure success. These critical roles to support EVCM is known as the Construction Management Project Model.
4.2. Methodology

The methodology applied in this chapter encompasses the use of statistical analysis of EV furnace data applying statistical decision theory, nonparametric testing, and descriptive statistics. The first part of the data requires descriptive statistical calculations of the mean, standard deviation, upper and lower confidence interval values. The second part is using a one-tailed t-test against the performance indices, the planned versus actual cost, and the actual cost before and during COVID-19.

The furnace data in this chapter is the data obtained before COVID-19 using the EVM method and during the COVID-19 pandemic applying the EVCM method. The statistical comparison of this data is compared to Table 3.6 and 3.7, before COVID-19, in chapter 3. The alternate comparison of the data uses the simulated values of applying the EVCM method. The statistical Alpha Level of 0.05 is the basis of the statistical analysis. The states of nature applied in the decision theory are (1) Do not use EVCM and accept the risk of cost and schedule impacts due to quality, (2) Use EVCM with the risk of 0.95 or higher is an acceptable risk, and (3) Do not use EVCM and accept the risk of 0.90 and higher as an acceptable risk for cost and schedule. The use of probabilistic criteria in the ultimate decision of which states of nature to best support the project.

The statistical testing uses the Alpha level of 0.05 to evaluate the probability values from the t-tests performed. The \( p \)-values and analysis determine the significance of the groups. The \( p \)-value that is less than 0.05 results in rejecting the null hypothesis and concludes there is a significant difference. The \( p \)-value greater than 0.05 concludes that we fail to reject the null and supports greater evidence for the null hypothesis. Researchers like to perform hypothesis testing to identify any significance of the data tested. The methodology of this chapter is to apply a one-
tailed t-test for actual cost, the actual cost divided by budget and the performance indices of the two groups of furnaces. The two groups of populations that are being tested are furnaces A through D, before COVID-19, and furnaces F through H during COVID-19. All furnaces were completed by the same contractors with the same scope. The work areas for the furnaces are located at the same plant area within Louisiana. The characteristics of the data are supported using statistical testing of one-tailed t-tests.

4.2.1. One-Tailed T-Test with Equal Variance Actual Cost

The actual cost data from Tables 4.1 and 4.2 is used to apply a one-tailed t-test with equal variance. The statistical analysis determines if the means of the actual cost of furnaces A through D are equal to furnaces F through H. The null hypothesis and alternate hypothesis are tested.

- **$H_0$: Furnace A-D Cost means is equal to Furnaces F-H means**
- **$H_a$: Furnace A-D Cost means is less than Furnaces F-H means**

### Table 4.1. Furnace A-D Cost Data

<table>
<thead>
<tr>
<th>Furnace</th>
<th>Budget</th>
<th>Actual</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$775,000</td>
<td>$832,711</td>
<td>$(57,711)</td>
</tr>
<tr>
<td>B</td>
<td>$775,000</td>
<td>$839,360</td>
<td>$(64,360)</td>
</tr>
<tr>
<td>C</td>
<td>$775,000</td>
<td>$832,995</td>
<td>$(57,995)</td>
</tr>
<tr>
<td>D</td>
<td>$775,000</td>
<td>$846,136</td>
<td>$(71,136)</td>
</tr>
<tr>
<td>Total</td>
<td>$3,100,000</td>
<td>$3,351,202</td>
<td>$(251,202)</td>
</tr>
</tbody>
</table>

### Table 4.2. Furnace F-H Cost Data

<table>
<thead>
<tr>
<th>Furnace</th>
<th>Budget</th>
<th>Actual</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>$894,225</td>
<td>$762,467</td>
<td>$131,758</td>
</tr>
<tr>
<td>G</td>
<td>$894,225</td>
<td>$775,562</td>
<td>$118,663</td>
</tr>
<tr>
<td>H</td>
<td>$894,225</td>
<td>$759,467</td>
<td>$134,758</td>
</tr>
<tr>
<td>Total</td>
<td>$2,682,675</td>
<td>$2,297,496</td>
<td>$385,179</td>
</tr>
</tbody>
</table>
4.2.2. Actual/Budget Cost One-Tailed T-Test with Equal Variance

The actual cost data from Table 4.3 is used to apply a one-tailed t-test with equal variance. The statistical analysis determines if the means of actual cost divided by the initial budget of furnaces A through D are equal to furnaces F through H. The null hypothesis and alternate hypothesis are tested.

- **$Ho$: Furnace A-D Actual/Budget means is equal to Furnaces F-H Actual/Budget means**
- **$Ha$: Furnace A-D Actual/Budget means is less than Furnaces F-H Actual/Budget means**

Table 4.3. Furnace A-H Actual/Budget Data

<table>
<thead>
<tr>
<th>COVID-19</th>
<th>Furnace</th>
<th>Budget</th>
<th>Actual</th>
<th>Cost Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>A</td>
<td>$775,000</td>
<td>$832,711</td>
<td>1.07</td>
</tr>
<tr>
<td>No</td>
<td>B</td>
<td>$775,000</td>
<td>$839,360</td>
<td>1.08</td>
</tr>
<tr>
<td>No</td>
<td>C</td>
<td>$775,000</td>
<td>$832,995</td>
<td>1.07</td>
</tr>
<tr>
<td>No</td>
<td>D</td>
<td>$775,000</td>
<td>$846,136</td>
<td>1.09</td>
</tr>
<tr>
<td>Yes</td>
<td>F</td>
<td>$894,225</td>
<td>$762,467</td>
<td>0.85</td>
</tr>
<tr>
<td>Yes</td>
<td>G</td>
<td>$894,225</td>
<td>$775,562</td>
<td>0.87</td>
</tr>
<tr>
<td>Yes</td>
<td>H</td>
<td>$894,225</td>
<td>$759,467</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Note: Greater than 1.0 equals over budget. Less than 1.0 is under budget.

4.2.3. TPI and TCONPI One-Tailed T-Test Unequal Variance

The data from Table 4.4 is used to apply a one-tailed t-test with unequal variance. The statistical analysis determines if the means of the performance indices of furnaces A through D are equal to furnaces F through H. There are evidentiary data that TPI is not accurate and not aligned as reported. To conclude there is a significance the one-tailed t-test is still conducted for further support. The furnace cost data in Table 4.1 indicated that they were all over budget. The null hypothesis and alternate hypothesis are tested.

- **$Ho$: TPI means is equal to TCONPI means**
- **$Ha$: TPI means is less than TCONPI means**
Table 4.4. TPI and TCONPI Analysis

<table>
<thead>
<tr>
<th>Group 1</th>
<th>TPI</th>
<th>Group 2</th>
<th>TCONPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>0.98</td>
<td>F-1</td>
<td>0.92</td>
</tr>
<tr>
<td>A-2</td>
<td>1.16</td>
<td>F-2</td>
<td>0.92</td>
</tr>
<tr>
<td>A-3</td>
<td>0.93</td>
<td>F-3</td>
<td>0.96</td>
</tr>
<tr>
<td>A-4</td>
<td>0.97</td>
<td>F-4</td>
<td>1.06</td>
</tr>
<tr>
<td>B-1</td>
<td>0.97</td>
<td>G-1</td>
<td>1.09</td>
</tr>
<tr>
<td>B-2</td>
<td>1.01</td>
<td>G-2</td>
<td>1.12</td>
</tr>
<tr>
<td>B-3</td>
<td>0.99</td>
<td>G-3</td>
<td>1.07</td>
</tr>
<tr>
<td>B-4</td>
<td>0.97</td>
<td>G-4</td>
<td>1.13</td>
</tr>
<tr>
<td>C-1</td>
<td>1.00</td>
<td>H-1</td>
<td>1.21</td>
</tr>
<tr>
<td>C-2</td>
<td>0.96</td>
<td>H-2</td>
<td>1.26</td>
</tr>
<tr>
<td>C-3</td>
<td>1.05</td>
<td>H-3</td>
<td>1.31</td>
</tr>
<tr>
<td>C-4</td>
<td>0.99</td>
<td>H-4</td>
<td>1.21</td>
</tr>
<tr>
<td>D-1</td>
<td>0.97</td>
<td></td>
<td>Average 1.11</td>
</tr>
<tr>
<td>D-2</td>
<td>1.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D-3</td>
<td>0.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D-4</td>
<td>0.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.99</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Through statistical testing and analysis, it is predicted that the improvements of EVCM are significant and concludes the rejection of the null hypothesis and failed to reject the alternative hypothesis. The alpha level this statistical testing uses is 0.05 with a confidence level of acceptance of 0.95. The data to be tested are seven furnaces that are equal in scope and using the same contractors who are experienced working in industrial construction. The first four furnaces were completed in 2019 before COVID-19. The other three furnaces were done during the early impacts of COVID-19 where uncertainty and risk mitigation was new to the United States and construction environments.

4.3. Construction Management Project Model

The Construction Management Project Model (CMPM) outlines the critical resources that are needed to efficiently execute a project employing the EVCM or EVM methods. The Project Management Office (PMO) is where the project initiation occurs, and the organizational leaders
determine if the project is valid and presents a return of investment for the stakeholders. The PMO then assigns a Project Manager (PM) and a Construction Project Manager (CPM).

The functions of both PM and CPM are similar as it relates to cost and schedule. However, the CPM is more of a technical professional regarding construction execution, schedule performance management, and construction performance of the contractor. The CPM reviews and recommends the outcome of all construction change orders. The CPM is knowledgeable of EVM and EVA methods. The PM is responsible for the cost outcome and reporting progress to the stakeholders. The CPM is assisted by an assigned scheduler, quality assurance owner representatives, and safety.

The contractor selected provides their staff. However, to influence the outcome of a project and provide efficient and valid EV data, the contractor provides at a minimum a project planner/coordinator, scheduler, quality control inspector, safety technician, and superintendent. The emphasis of these indirect staff members is to accurately and validate the scope and specifications of the bid documents into a usable and reliable work plan and schedule. The table of organization needed to employ EVM or EVCM is outlined in Figure 4.1.

![CMPM Organizational Chart](image)

Figure 4.1. CMPM Organizational Chart
4.3.1. Construction Project Scope Management

Project scope is an important piece of the project [5]. When a contractor is bidding on an industrial construction project, this piece of information assists the bidding contractor to put a cost to an activity called out in the Issue for Construction (IFC) documents, also known as the bid documents. In this phase, the main objective is to provide a full description of the project and list all the required deliverables [76]. Without a clear understanding of the deliverables from the PMO to the project team and then to the selected contractor incur a costly project full of change orders [76]. In project management, the project scope development can be outlined in six steps [5, 76]. Figure 4.2 outlines these steps.

Figure 4.2. Scope Management Process [5, 76]

4.3.2. Construction Project Schedule Management

Schedule Management in projects requires the equilibrium of time, budget, quality, risk, scope, resources, and constraints [4, 5, 21]. The implementation of a project often sees impacts and field change orders that were not captured in the original scope [5]. To execute the project effectively, the project team relies on a work breakdown structure that is inputted into a scheduling system. The schedule becomes one of the basic requirements of project management in the execution of the project [4, 5, 64, 77].
The schedule begins in the planning and front-end loading of a project. The scheduling is integrated with other constraints such as budget, scope, and resources. The baseline schedule must validate the overall duration and man-hours outlined in the agreed contract. However, the constraints must be managed to meet the project deliverables. The project schedule is an outline of all the construction activities to be executed. The schedule can also be used as a reporting tool for the project’s progress. The data in the schedule with the progress reporting is used to develop EV metrics to conduct EV analysis. The process of performing construction project schedule management is outlined in Figure 4.3.

![Figure 4.3. Construction Project Schedule Management](image)

**4.3.3. Construction Project Cost Management**

Construction Project Cost Management is one of the key pillars within the Project Management principles outlined in the PMBOK. Cost management in a project is the process of estimating, budgeting, and controlling the costs within the project life cycle. The success of cost management is measured against the project budget, planned values, and progress. For example, we are in week two of a construction project that is planned for four weeks at a project value of $300,000. The planned value to be spent is $150,000 and progress of 50% complete. However, the project is 40% complete with a spent value of $150,000. This is not
uncommon that a project is underestimated with planned values not being met. In a cost-plus contract, the owner normally makes up the difference. The expense and financing of a new contractor would be more costly than to just pay the difference in what is needed to complete. In a lump sum, the contractor who agreed to a set dollar amount is normally responsible unless they can make a good case for a change order to cover the loss.

The leading authority for global standards is the International Organization for Standardization (ISO). The ISO standard exists for quality, environmental, construction safety, and risk management but none exists for project cost management. There are plenty of professional associations for project cost management professionals. The International Construction Measurement Standard (ICMS) is attempting to standardize project cost management in a global standard. The fundamental role in project cost management is to control and manage the costs of a project through the project life cycle. One way this is managed is through EV metrics, such as the CPI and SPI.

The development of infrastructure through construction is vital to economic growth and societal advances. Flyberg et al. reported in their study of transportation projects, that 90% of those construction projects had cost overruns and impacted by inefficient estimating practices. Many construction projects suffer the fate of not being complete within the budget. The improvement of construction project cost management is not only necessary but vital for historic data that is used on similar projects that suffer the same fate if not accurately reported or tracked.

4.4. Application of EVCM

The application of EVCM, from chapter 3, is an improved method of EVM that incorporates a new performance index derived from quality control performance. There is always
The EVCM method now incorporates quality in the project management process. There is an inclusion of new terms, equations, and results to analyze the project. In most construction projects, the construction project manager wants to know CPI and SPI. The CPI is tied to cost while SPI is tied to a schedule. The new earned value performance index, QSPI, measures the quality control plan’s performance and the completion of those activities outlined in the ITP. The quality control inspection and testing activities are added to the schedule to progress and calculate the QSPI. The EVCM process now uses CPI, SPI, and QSPI to calculate the total performance index of the project’s overall health (TCONPI). The example of calculating the TCONPI and other EVCM methods is in Table 3.2.

4.5. Furnace Case Study

The case study demonstrates the EVA technique for four furnaces’ weekly construction performance. The four furnaces included in this case study, (e.g., Furnace A, Furnace B, Furnace...
C, and Furnace D) are equal in size, equal in scope and location, and use the same contractors. The furnaces were completed in 2019. The furnace’s scopes of work and budgets are also equal. Each furnace’s general scope of work includes civil, mechanical, pipe and valve install, instrument, and electrical cabling. Furnaces in industrial plants are an intricate and vital piece of equipment in industrial processes [70, 71]. Organizations in the industrial sector must take full advantage of supply and demand by improving the maintenance, repair, and modernization of furnaces with improved technologies [72]. The market demand requires that the furnaces operate at full capacity and not trip by shutting down due to safety automation [70]. The rise in energy costs influences heat recovery by employing new technologies and design [70, 71, 73].

The furnace data presented in Tables 4.5 and 4.6 represents the mean weekly construction performance for each performance index. To comply with proprietary data restrictions, the work scope for all the furnaces in this case study is equal, and the contractors performing the work are the same. To apply the basics of EVA, the furnace data in Table 4.5 in this case study centers around the basic methods of EVM. There are many earned value software packages that automatically calculate these indices [74]. Most construction organizations utilize Primavera 6 or MS Project to provide the EVM indices. However, depending on the scheduler’s experience level and understanding of EVM calculations continues to be a problem in using EVM [3, 7, 18, 21]. In industrial construction, the lead scheduler must be well versed in EVM.

Certain elements of the project, such as soil compaction, concrete strength, welding of pipe and flanges, installation of valves, torque bolting, I/O testing of terminations and instruments, and pipe pressure testing, are traditionally checked or tested by third-party testing and inspection organizations. These prescribed tests are conducted before and during the
construction project. The quality of other project elements is examined by the project engineer and design team, or one of the owner’s quality managers.

4.6. Discussion and Results

The contribution of this chapter and the result of the statistical analysis demonstrates that the EVCM method is an improvement. The statistical t-test results in Table 4.7 conclude that all three t-tests are significant. The t-test results in Table 4.7 for actual cost and actual cost/budget resulted in p-values less than 0.0001. The conclusive result is the rejection of the null hypothesis that the means are equal. This supports that there is cost improvement using the EVCM method. The t-test result for the performance indices hypotheses is that the mean of the Total Performance Index is equal to the mean of the Total Construction Performance Index using the EVCM method. The p-values from Table 4.7 reject the hypothesis of all three t-tests that they are equal and fail to reject the alternate hypothesis that they are not equal. The statistical analysis of the three t-tests points to the improved significance of applying EVCM. The high probability of success using EVCM improves project and cost performance expected of stakeholders.

In Table 4.3, the data shows that the means for traditional TPI = 0.99 where the means for the EVCM TCONPI = 1.11. The data collected from three furnaces during COVID-19 had constraints of social distancing, added PPE, and approximately 5% inefficiency factor. The data collected from four furnaces before COVID-19 had limited to no constraints. The variance of means of TPI and TCONPI is 0.12. The contribution of applying EVCM significantly improves the overall progress of a project. The radar plot is shown in Figure 4.4 also confirms that the EVCM method shows productivity increases, therefore, improving on schedule performance. The radar plot also indicates the separation and gaps of the EVCM versus the traditional performance index data. The analysis of Table 4.8 shows the overages of man-hours needed for
furnaces A through D as compared to furnaces of F through H. This analysis is in alignment with the cost analysis performed in Tables 4.1 and 4.2. The cost overage to the budget for furnaces A through D in Table 4.1 increased by $251,202. The cost savings utilizing EVCM resulted in a cost reduction of $385,179 as indicative in Table 4.2 and Figure 4.5. The additional man-hours needed for furnaces A through D resulted in 1,794 for the four furnaces. This is an increase of 8% of the budgeted man-hours. For furnaces F through H, applying EVCM, the results were much more positive with a decrease of 239 needed man-hours, refer to Figure 4.6. Using EVCM in a non-COVID environment has a high probability of reducing 400 or more man-hours per furnace.

Table 4.5. EVM Data before COVID-19

<table>
<thead>
<tr>
<th>Furnace</th>
<th>CPI</th>
<th>SPI</th>
<th>TPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Week 1</td>
<td>0.96</td>
<td>1.00</td>
<td>0.98</td>
</tr>
<tr>
<td>A-Week 2</td>
<td>1.20</td>
<td>1.11</td>
<td>1.16</td>
</tr>
<tr>
<td>A-Week 3</td>
<td>0.86</td>
<td>0.99</td>
<td>0.93</td>
</tr>
<tr>
<td>A-Week 4</td>
<td>0.95</td>
<td>0.98</td>
<td>0.97</td>
</tr>
<tr>
<td>B-Week 1</td>
<td>0.96</td>
<td>0.98</td>
<td>0.97</td>
</tr>
<tr>
<td>B-Week 2</td>
<td>1.02</td>
<td>0.99</td>
<td>1.01</td>
</tr>
<tr>
<td>B-Week 3</td>
<td>0.97</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>B-Week 4</td>
<td>0.98</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>C-Week 1</td>
<td>1.01</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>C-Week 2</td>
<td>0.96</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>C-Week 3</td>
<td>1.10</td>
<td>1.00</td>
<td>1.05</td>
</tr>
<tr>
<td>C-Week 4</td>
<td>0.98</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>D-Week 1</td>
<td>0.97</td>
<td>0.96</td>
<td>0.97</td>
</tr>
<tr>
<td>D-Week 2</td>
<td>0.99</td>
<td>1.10</td>
<td>1.05</td>
</tr>
<tr>
<td>D-Week 3</td>
<td>0.95</td>
<td>0.98</td>
<td>0.97</td>
</tr>
<tr>
<td>D-Week 4</td>
<td>0.93</td>
<td>1.00</td>
<td>0.97</td>
</tr>
</tbody>
</table>
Table 4.6. EVCM Data during COVID-19

<table>
<thead>
<tr>
<th>Furnace</th>
<th>CPI</th>
<th>SPI</th>
<th>QSPI</th>
<th>TCONPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-Week 1</td>
<td>1.39</td>
<td>0.50</td>
<td>0.88</td>
<td>0.92</td>
</tr>
<tr>
<td>F-Week 2</td>
<td>1.27</td>
<td>0.60</td>
<td>0.89</td>
<td>0.92</td>
</tr>
<tr>
<td>F-Week 3</td>
<td>1.30</td>
<td>0.66</td>
<td>0.92</td>
<td>0.96</td>
</tr>
<tr>
<td>F-Week 4</td>
<td>1.20</td>
<td>1.00</td>
<td>0.99</td>
<td>1.06</td>
</tr>
<tr>
<td>G-Week 1</td>
<td>1.10</td>
<td>1.21</td>
<td>0.96</td>
<td>1.09</td>
</tr>
<tr>
<td>G-Week 2</td>
<td>1.20</td>
<td>1.18</td>
<td>0.98</td>
<td>1.12</td>
</tr>
<tr>
<td>G-Week 3</td>
<td>1.00</td>
<td>1.23</td>
<td>0.99</td>
<td>1.07</td>
</tr>
<tr>
<td>G-Week 4</td>
<td>1.40</td>
<td>1.00</td>
<td>0.99</td>
<td>1.13</td>
</tr>
<tr>
<td>H-Week 1</td>
<td>1.60</td>
<td>1.10</td>
<td>0.93</td>
<td>1.21</td>
</tr>
<tr>
<td>H-Week 2</td>
<td>1.74</td>
<td>1.09</td>
<td>0.95</td>
<td>1.26</td>
</tr>
<tr>
<td>H-Week 3</td>
<td>1.88</td>
<td>1.08</td>
<td>0.98</td>
<td>1.31</td>
</tr>
<tr>
<td>H-Week 4</td>
<td>1.65</td>
<td>1.00</td>
<td>0.99</td>
<td>1.21</td>
</tr>
</tbody>
</table>

Table 4.7. One-Tailed T-Test Results

<table>
<thead>
<tr>
<th>T-Test</th>
<th>p-value</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Cost</td>
<td>0.000025</td>
<td>reject the null hypothesis that they are equal</td>
</tr>
<tr>
<td>Actual Cost/Budget</td>
<td>0.000002</td>
<td>reject the null hypothesis that they are equal</td>
</tr>
<tr>
<td>TPI vs TCONPI</td>
<td>0.002530</td>
<td>reject the null hypothesis that they are equal</td>
</tr>
</tbody>
</table>

Note: All p-values are less than 0.05 and support a strong significance towards the alternative hypothesis.

Table 4.8. Furnace A-H Man-Hour Analysis

<table>
<thead>
<tr>
<th>Furnace</th>
<th>Planned MHRs</th>
<th>Actual MHRs</th>
<th>Earned MHRs</th>
<th>Earned % (+/-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5539</td>
<td>5951</td>
<td>-412</td>
<td>1.074%</td>
</tr>
<tr>
<td>B</td>
<td>5539</td>
<td>5999</td>
<td>-460</td>
<td>1.083%</td>
</tr>
<tr>
<td>C</td>
<td>5539</td>
<td>5953</td>
<td>-414</td>
<td>1.075%</td>
</tr>
<tr>
<td>D</td>
<td>5539</td>
<td>6047</td>
<td>-508</td>
<td>1.092%</td>
</tr>
<tr>
<td>F</td>
<td>6739</td>
<td>6630</td>
<td>109</td>
<td>-1.6%</td>
</tr>
<tr>
<td>G</td>
<td>6739</td>
<td>6744</td>
<td>-5</td>
<td>1.001%</td>
</tr>
<tr>
<td>H</td>
<td>6739</td>
<td>6604</td>
<td>135</td>
<td>-2.0%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>49112</td>
<td>51394</td>
<td>-2282</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 4.4. Radar Plot of TPI vs TCONPI

Figure 4.5. Furnace A-H Planned versus Actual Cost
4.7. Conclusion

In conclusion, EVM is used to analyze the project performance, calculate the variance for schedule and cost, and indicate the project health compared to the baseline estimates [3, 7, 9, 12]. EVM’s potential reasons for promising outcomes include improved work efficiencies, fewer rework required, limited field change orders, reduced engineer errors and omissions, and work scope not as complex as previously understood [4, 6]. However, if not applied effectively or at all, you can expect cost overruns, scope creeps, push and pull management decisions with limited data, increased costs, and late schedule completion [29].

When the project adequately manages all critical elements of the construction process to include quality and safety, the outcome has a high probability of a successful project. Evidently, with the enhanced controls and including the quality control and safety activities in the schedule that are part of a complete quality control plan, the project has fewer problems to fix and higher
quality levels from start to finish. By including, tracking, and reporting all elements of the quality control plan, the construction project manager is fully aware that the successor construction activity can begin as planned. The construction project manager knows with a high level of certainty the current activity is complete, and no re-work is required.
Chapter 5. Conclusions

5.1. Introduction

The challenges and uncertainties of COVID-19 critically exposed the immediate need for improving the traditional EVM method and prescribe an effective standard of safety protocols to overcome the health hazards of a pandemic. The construction safety culture in the U.S. is constantly evolving progressively to reduce injury and loss of life. The havoc that COVID-19 caused on the construction industry vitally impacted quality and safety aligned to increased cost and duration in the schedule. The objective of this dissertation research was to prescribe effective construction safety protocols and PPE and purpose the cost and schedule implications during a pandemic. The central goal was to improve the traditional Earned Value Management method by incorporating quality control and safety into the schedule for more accurate project reporting. The development of the EVCM method that incorporates quality and safety control activities into the schedule producing a new index (QSPI) that satisfies the completion of the goal and objectives. The supporting objectives to influence these dissertation goals are:

- Evaluate the effectiveness of social distancing, sanitization methods, additional PPE in an industrial construction environment. In addition, record and evaluate the cost and schedule impacts of these new requirements during the COVID-19 Pandemic.

- Incorporate quality control activities into the schedule and improve the traditional EV method to be tailored to industrial construction. The improved method is called the EVCM method. Test the EVCM through simulated alpha levels to show the impacts on the TPI.

- Demonstrate the value of EVCM by statistical testing data of traditional EV versus EVCM data of actual collected furnace construction data. The data collected is from before COVID-19 and during COVID-19.
The foundation work to support the purpose and objectives of this dissertation is evident in Chapters 2 through 4. Each chapter presents the methodology, results and data, and conclusion. The subsequent sections of this chapter summarize the results and conclusions of each chapter.

5.2. Industrial Construction Safety Policies and Practices in a Pandemic

The U.S. during COVID-19 transitioned from containment to mitigation protocols through social distancing and isolation of infected persons by quarantining. None of the practices briefly described in this dissertation go without a price and schedule impact. The impact was not easy to determine as there is no data for cost during a pandemic. The PPE listed in this dissertation was difficult to obtain as supplies were quickly diminishing due to priority going towards healthcare and first responders. In March, we saw an increase in cases and outbreaks. A study published in April 2020 reported that 8.3% of the 5.9 million construction workers during the pandemic would be exposed once a month [33].

The act of sneezing or coughing can produce 3,000 to 40,000 droplets in the form of large, small, aerosol, and nuclei droplets [47]. These droplets can travel up to 6.6 feet for coughing and as far as 19.8 feet for sneezing [47]. The findings of this data influenced the requirement to wear protective masks or face shields. The recommend social distancing from WHO, CDC, and LDH influenced the risk mitigation protocol in preventing the spread of COVID-19. The cost of implementing these safety protocols for a four-week project that uses 40 workers can be an increase of $119,225 U.S. Dollars. Due to inefficiencies of wearing extra PPE and delays in getting permits could potentially add 3 days to the schedule.
5.3. Earned Value Construction Management Method

The EVCM method presented enhances the project’s ability to truly gauge and report the success by incorporating quality and safety, a missing essential element of construction reporting. The problem statement of how to collectively capture, track, and report under one reporting mechanism is ultimately linked in the schedule. The EVCM method satisfies this desire and provides an added tool for construction project managers in industrial construction. The problem statement of capturing and reporting quality issues in a project is now answered in the EVCM method. The importance of a successful project is cost, duration, quality, and safety. The statistical t-test results in Table 4.7 regarding cost, budget, and project performance resulted in all $p$-values being less than 0.05 testing the means of furnaces A through D before COVID-19 and furnaces F through H during COVID-19. The statistical result is rejecting the null hypothesis that the data before COVID-19 is equal to the data during COVID-19 for cost and performance. The results also conclude there is a positive significance of applying the EVCM in industrial construction.

5.4. EVCM Application Before and During a Pandemic

The statistical results showed significance to support that the EVCM method is an improvement to the traditional EV method. The null hypothesis stated that the TPI means is equal to the TCONPI mean, which was rejected due to the alpha level value being less than 0.05. The statistical result is rejecting the null hypothesis and failed to reject the alternative hypothesis. The t-tests results in Table 4.7 supported that the means of EV and EVCM are not equal. This result indicates that the data are significantly different. The statistical testing uses an alpha level of 0.05. The $p$-value outcomes for all three t-tests were less than 0.05 as evident in Table 4.7, thus supporting it as statistically significant. The t-test for performance had vulnerabilities in that
TPI is not accurate for furnaces A through D. The budget versus the actual costs shown in Table 4.1 shows an overage of $251,202. However, in Table 4.4 TPI average is 0.99, which indicates the project is on schedule and within budget and that is not the case.

The data presented in Table 4.6 shows the QSPI affecting the TCONPI with increasing improvement in performance and productivity. In Table 4.4, the data exhibits a comparison analysis between TPI and TCONPI. The analysis shows TPI is surpassed by TCONPI due to reduced man-hours needed because of not having re-work. The planned budget for furnaces A through D is $3,100,000 but the actual cost of construction is $3,351,202 shown in Table 4.1. This is an 8% increase in cost. In Table 4.1, the cost analysis shows that the budget was exceeded by $251,202. However, the actual cost for furnaces F through H had a $385,179 savings utilizing the EVCM method observed in Table 4.2.

The total man-hours for a furnace before COVID-19 account for 5,539 man-hours. However, applying the EVCM method, the man-hours increase to a total of 6,739 man-hours. The increase in hours accounts for the QSPI activities recorded in the schedule. These additional hours do not increase the budget as these hours are mostly accounted for in the overall budget but not in the schedule. The cost increase in the budget in Table 4.2 accounts for COVID-19 compliance costs. However, the earned value impact for furnaces A through H has an average increase of 8.1% observed in Table 4.1. The man-hour reduction for furnaces F through H was observed at 239 man-hours in Table 4.8.

5.5. Final Remarks and Recommendations

The industrial construction industry employs the most up-to-date methods and personal protective equipment to ensure safety on the construction site. The safety methods and practices come with a cost and an impact on productivity. The resolution for reducing the impacts on
productivity is the utilization of an improved Earned Value method in schedule performance management. The data presented in this dissertation concerning using facial coverings, face shields, social distancing, and sanitization practices strongly supports the effective methods in reducing the spread of a virus during a pandemic. Instituting most to all the COVID-19 safety protocols in this dissertation mitigate the spread of viruses allowing construction workers to support critical infrastructure projects. The cost and schedule data during COVID-19 assist industrial construction companies in confidently estimating during the bid process. The data supports there are productivity inefficiencies and the need for additional resources that increase project cost and add days to the overall schedule.

Before and during COVID-19, the overarching desire to capture and reduce cost overruns associated with poor construction quality is vitally important. The proposed solution to bridge the gap requires an improved Earned Value method in construction project management. The solution proposed in this dissertation is the EVCM method. The EVCM method is tailored to industrial construction and adds quality control activities to the schedule. The quality control activities are derived from the ITP of the project. The progressing of the quality control activities then populates the QSPI, which is integrated into the overall performance index. The scientific question is the EVCM method an improvement? To test this hypothesis, a one-tailed t-test is conducted on furnace data before and during COVID-19.

The traditional EV is statistically tested against the improved EVCM method for cost and performance indices. The research question is answered in that the data tested is statistically significant. The EVCM method provides a more accurate performance index of the health of a project that includes quality control activities. The EVCM method influenced an over 1.0 overall performance index. This higher than 1.0 index pointed towards gradually reduced float in the
schedule while influencing fewer resources needed. The quality control activities aligned with
the critical path in the schedule reduced the amount of re-work not traditionally reported. The
EVCM method in this dissertation undoubtedly provides a significantly more accurate index than
the traditional EVM method. The proven EVCM method bridges the quality gap of including and
reporting on quality control activities within the construction schedule. The EVCM method also
captures and reports a performance index aligned to quality activities that traditionally increase
the project budget and duration. This increase is notable in Tables 4.1 and 4.2 where the increase
in cost under the EV method is trending over budget as compared to the EVCM that accounts for
cost savings across three furnaces. Regarding man-hours planned versus actual, the impact is an
8.1% increase under the EV method compared to -1.2% under budget applying the EVCM
method. The traditional EV method was challenged in accounting for 1,794 additional hours for
furnaces A through D as compared to reducing by 239 man-hours for furnaces F through H under
the EVCM method. The EVCM method becomes an added tool for project and construction
managers to report to stakeholders and owners more accurately with a higher degree of
confidence.
Appendix. Example Schedule with Quality and Safety Activities
References


Vita

Brian Briggs was born at Landstuhl Army Hospital, works as a Construction Project Manager in Baton Rouge, Louisiana after retiring from the military as a Major. He was commissioned in the U.S. Marine Corps in 1998 after completing Officer Candidate School in Quantico, Virginia. He also served six years enlisted before commissioning. He is a combat veteran who served in Desert Storm, Desert Shield, Global War on Terrorism, Iraq Freedom, and Combined Joint Task Force-Horn of Africa. He received his M.B.A. from Columbia Southern University in 2015 and his M.S. in Construction Management from Louisiana State University in 2019. Upon completing his second master’s degree, he immediately applied and was accepted into the Ph.D. Engineering Science program with Louisiana State University College of Engineering. Brian has over 23 years of experience in construction project management working in federal and state, commercial, residential, chemical, and petrochemical construction environments.