Evaluating the Impact of Using Agile Methodologies in Heavy-Civil Construction

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Evaluating the Impact of Using Agile Methodologies in Heavy-Civil Construction

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Dedication

This Praxis is dedicated to my mother who has at all times been my greatest foundation of support, pushing me to achieve at all levels. Mom, my achievement is your success.

Acknowledgements

The author wishes to thank Dr. Thomas Holzer, Dr. Andy MacDonald, and Doctoral Candidate Anil Sezer for their support throughout this entire process. I could not have done it without your help and guidance.

Abstract of Praxis

Evaluating the Impact of Using Agile Methodologies in Heavy-Civil Construction

Due to a lack of actual data-based research, industry-wide implementation of agile methodologies on heavy-civil construction projects is lacking, leading to management and performance issues that cause inefficient project delivery. As acknowledged by F. Ribeiro (2010), “Despite the amount of research work on agile concepts and the methods proposed by several authors, there is a striking absence of real applications of those concepts and models in the construction industry. Most of the publications highlight the theoretical aspects of agility without relating to specific real-world organizational environments.” (p. 167).

Heavy-Civil Construction focuses on highways, roads, bridges, tunnels, underground utilities, and other large public works projects. Such work can be new construction, replacement, maintenance, repair, and improvements for use by the general public. With this comes a set of unique challenges, requiring an extremely focused and skilled management team. Issues involving cost, schedule, quality, and safety are most important and steps are typically taken to minimize problems relating to these using a waterfall management approach to build the job. The common theory is that the introduction of agile methodologies would have a positive effect on the efficiency of these projects for all involved (Mendez, 2018).

Various references believe that by implementing agile methodologies on heavy-civil construction projects, the construction team has a better chance for a successful build by minimizing issues relating to the Key Performance Indicators of cost, schedule, quality, and safety (Owen & Koskela, 2007). The following quote by F. Ribeiro (2010)

also sums the beliefs referenced; “It is assessed that agile methods offer considerable potential for application in construction and that there are significant hurdles to its adoption in the actual phase. Should these be overcome, agile methods offer benefits well beyond any individual company.” (p.174).

After reviewing cost and incident data for 40 projects that utilized the waterfall approach of project management and comparing them to 40 projects that implemented agile methodologies, there is evidence to support a sound conclusion. This study shows both quantitatively and qualitatively that there is an improvement in project performance and overall success on those projects analyzed herein that utilized agile methods, thus presenting evidence to support the existing theories.

Keywords: Agile, Waterfall, Management, Project Performance Improvement, Heavy-Civil, Construction

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List of Acronyms

KPI	Key Performance Indicator
PSI	Project Success Index
PPV	Project Performance Value
PCP	Project Cost Performance
PTP	Project Time Performance
PQP	Project Quality Performance
PHP	Project Health, Safety, and Environment Performance
HSE	Health, Safety, and Environment
PCS	Project Client Satisfaction
BCost	Bid Cost
FCost	Final Cost
BP	Bid Profit
BWD	Bid Working Days
FP	Final Profit
FWD	Final Working Days
PM	Project Manager
RQ	Research Question
H	Hypothesis
OC	Original Constant

List of Symbols

C_{Delta}	Change in Cost from Bid to Final
P_{Delta}	Change in Profit from Bid to Final
$C_{TProject}$	C_{Delta} - P_{Delta}
C_{Sched}	Cost due to Schedule Issues
C_{Qual}	Cost Due to Quality Issues
C_{Safe}	Cost Due to Safety Issues
WPSI	Waterfall Project Success Index Data
APSI	Agile Project Success Index Data
WPPV	Waterfall Project Performance Value
APPV	Agile Project Performance Value
CAPSI	Corrected Agile Project Success Index Data
CWPSI	Corrected Waterfall Project Success Index Data
WSched	Waterfall Schedule Data
ASched	Agile Schedule Data
WQual	Waterfall Quality Data
AQual	Agile Quality Data
WSafe	Waterfall Safety Data
ASafe	Agile Safety Data
WCost	Waterfall Cost Data
ACost	Agile Cost Data

Chapter 1—Introduction

"In the successful organization, no detail is too small to escape close attention"

- Lou Holtz

1.1 Background

Heavy-civil construction project management typically follows a top-down or waterfall management process, with specific sequences and command and control structures developed and implemented in order to complete the project on time and under budget. Per Rapagna (2018), "Waterfall is how project management in construction works." (p. 1).

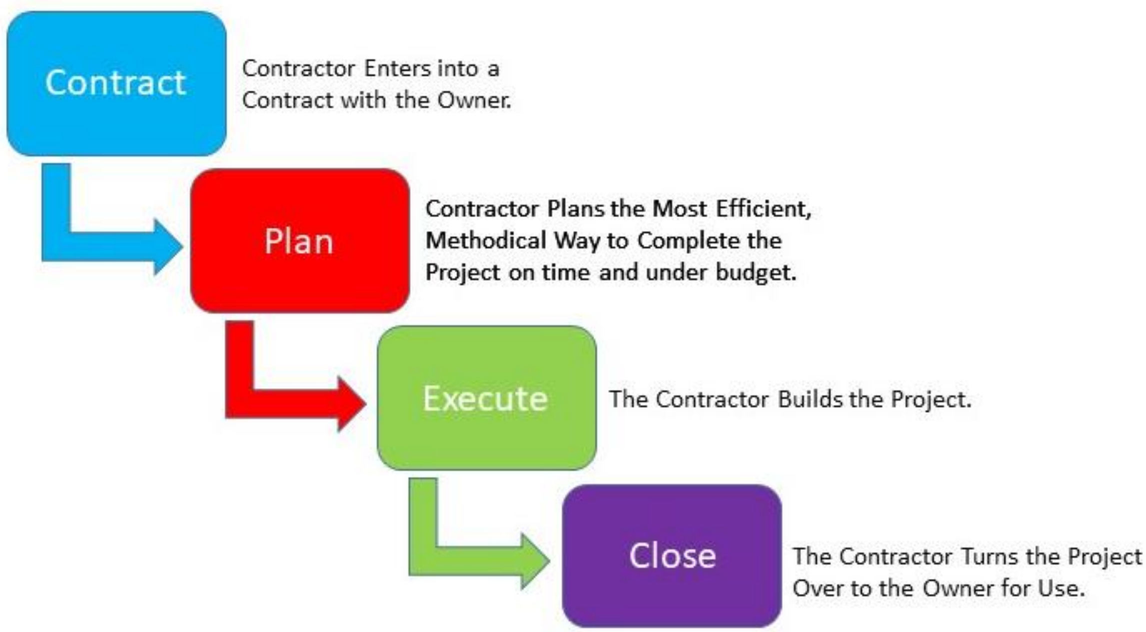

Figure 1-1. Waterfall Method.

As shown in Figure 1-1. *"Waterfall Method"*, the waterfall method focuses on a linear, top-down approach where past actions are rarely revisited and lessons learned are typically not reviewed, researched, or recognized until the end of the project. Per the research, a linear strategy is a traditional strategy that consists of dependent sequential phases that are executed with no feedback loops. The project solution is not released until the final phase (Fernandez et al, 2008).

Although not an industry standard, agile methodologies, such as the one shown in Figure 1-2. *"Agile Methodology"*, have been introduced and utilized in heavy-civil construction. In the agile loop shown, the first step taken is for the team to establish the processes that will be followed by all for any given task. Next, functional teams are identified that will focus on the individual activities. The scrum or daily update meeting follows to continually review and update progress and task completion. New assignments or sprints are regularly assigned to the functional groups and finally, processes and procedures are reviewed to improve the overall progression.

To date, some contractors and design-build teams have introduced aspects of the scrum, sprint, and functional teams on their projects with success (Daneshgari, 2006). Additionally, survey research has been conducted that predicts that the implementation of agile on construction projects would be beneficial. Per F. Ribeiro, (2010), "It is assessed that agile methods offers considerable potential for application in construction. Small, multidisciplinary project teams formed with the most skilled, empowered and highly motivated people and short, frequent meetings with all team members can help to increase efficiency." (p. 175).

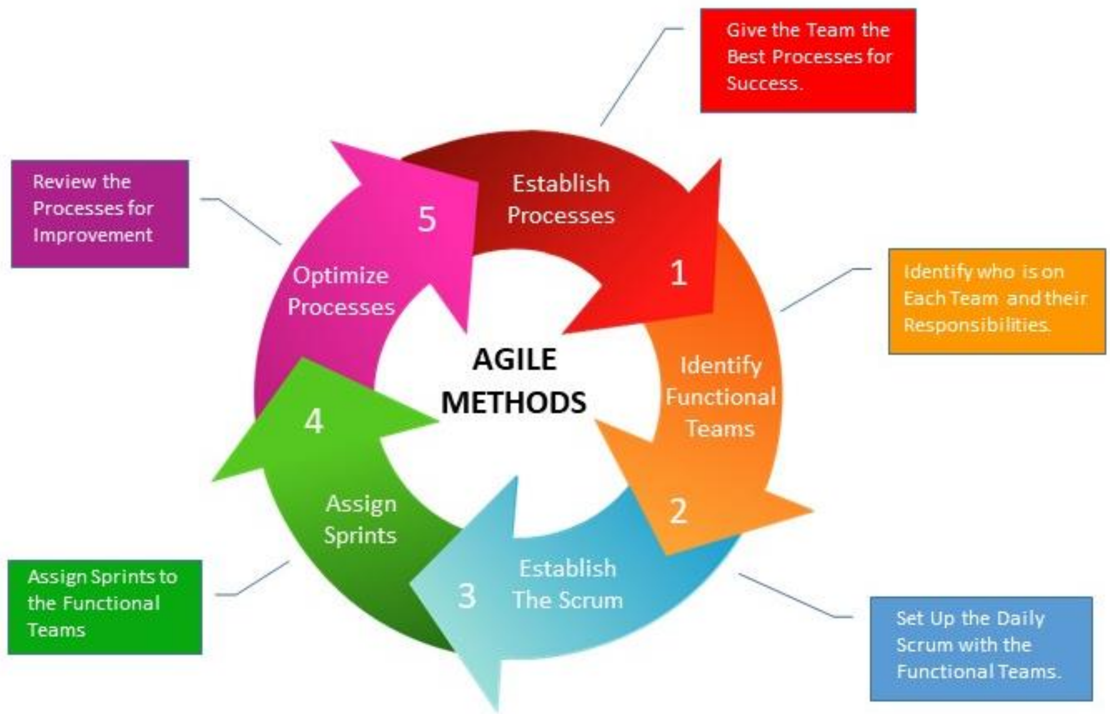

Figure 1-2. Agile Methodology. Adapted from "Delivering on Quality with Agile Software Development". (Davis, 2017)

Although survey studies have been done on the application and success of agile in construction, few studies have considered actual data from projects to compare those that have and have not implemented agile methodologies (Owen and Koskela, 2007). As F. Ribeiro (2010) states "Despite the amount of research work on agile concepts and the methods proposed by several authors, there is a striking absence of real applications of those concepts and models in the construction industry. Most of the publications highlight the theoretical aspects of agility without relating to specific real-world organizational environments." (p. 167-168).

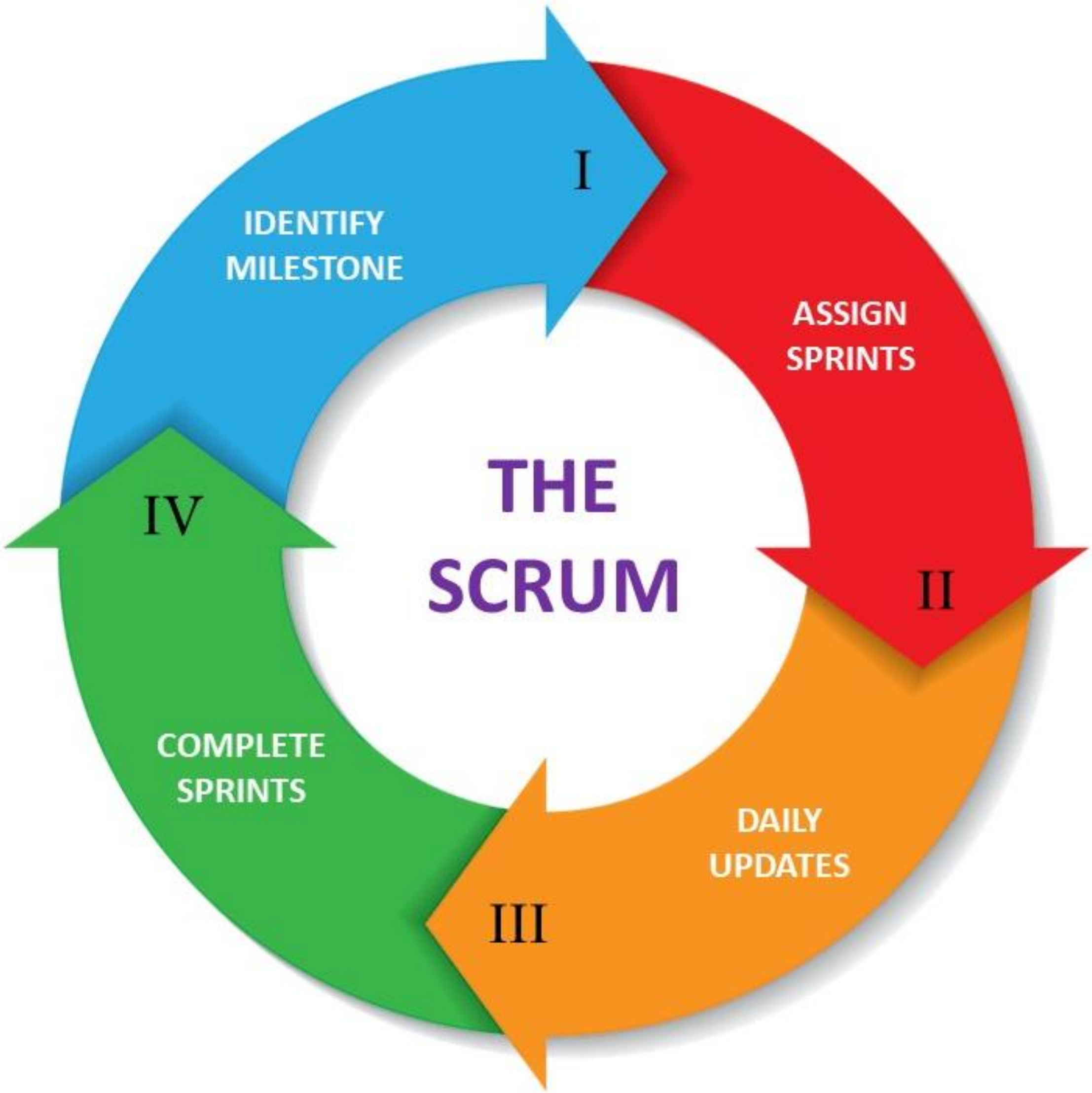

Figure 1-3. The Scrum. Adapted from "Peeking Behind the Curtain of Advantage QA". (Weissman, 2016)

Figures 1-3. *"The Scrum"* and 1-4. *"The Sprint"* present illustrations of the scrum methodology and how the sprint fits into the process. Essentially, the sprint is a single task or group of related tasks that are assigned to a functional team. This team gives daily updates regarding progress at the scrum meetings, allowing all interested parties a chance to track updates, offer advice, and participate in the process from start to finish. As presented by Streule et al (2016), "Mentioned benefits of scrum were a higher transparency, better communication and collaboration, better flow of information and faster project development." (p. 275), showing how the application of the scrum in construction was beneficial.

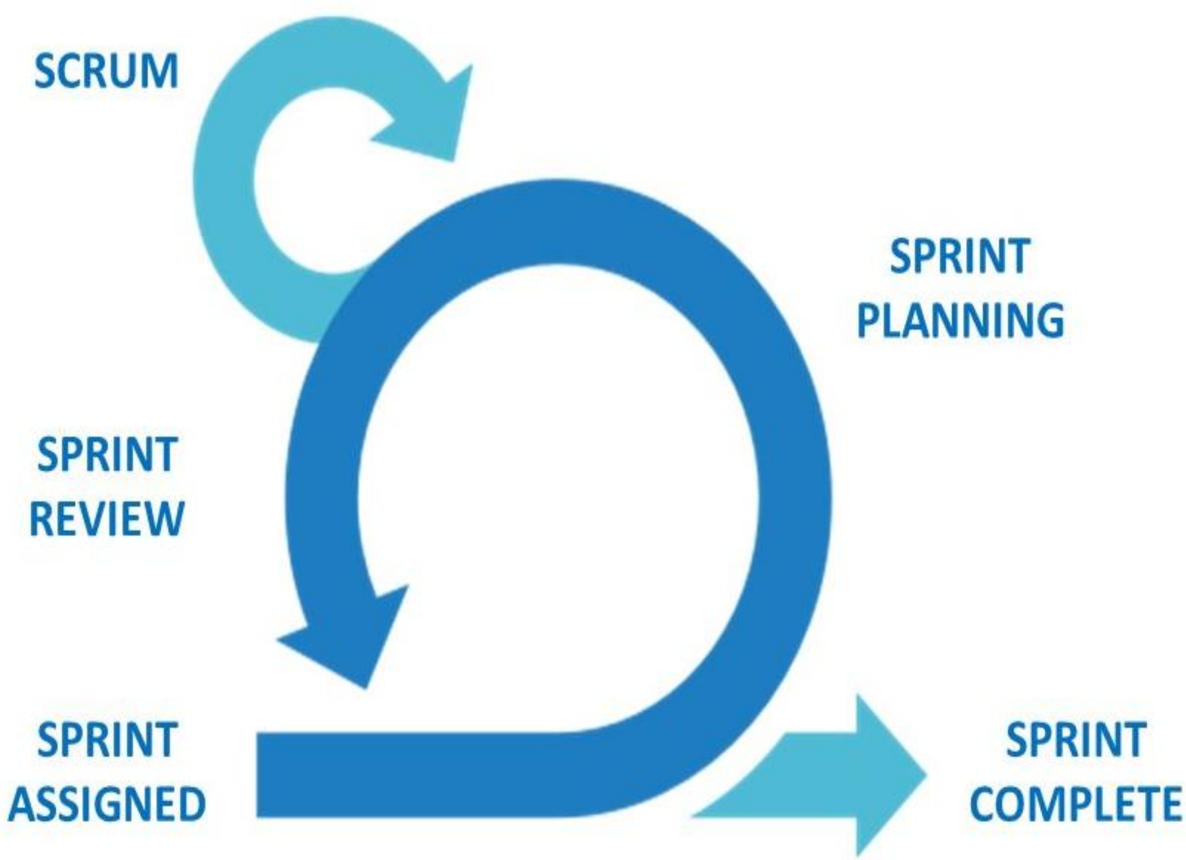

Figure 1-4. The Sprint. Adapted from "UX and Agility 1 Sprint Ahead". (Kuter, 2018)

As detailed in Figure 1-4. *"The Sprint"*, the sprint or task is assigned to the functional group, and the process of planning/execution begins. Using the daily scrum and sprint review, the process is ongoing until the entire task is complete and accepted by all. It should be recognized that multiple sprints or tasks can be on-going and most tasks won't be completed at the same time.

According to Streule et al (2016), their study showed other potential areas of benefits to the construction team as "Daily scrum could be beneficial to inform construction companies about the work progress and the daily goal (sprint) of other construction companies also working on site." (p. 276). Obviously, the more involved the complete team is on a day-to-day basis, the more in tune they will be with the overall progress of the project and how their work impacts the overall completion of the job.

1.2 Research Motivation

The research motivation of this study is to present actual, real-world project data from top-down, linear, waterfall-type managed projects and compare them to those that have implemented agile methodologies similar to the Daily Scrum, Sprints, and Functional Teams to the construction process. Ultimately, the objective is to determine the advantages and/or disadvantages of introducing agile methodologies to heavy-civil construction projects. The goal is to "put to test" the multiple studies done via surveys and single-project experiments that predict the benefits of using agile methods by evaluating those that have actually used them and seeing what, if any, benefits were realized. Essentially, the study aims to further prove that the prior research is valid.

1.3 Problem Statement

Due to a lack of actual quantitative research, implementation of agile methodologies on heavy-civil construction projects is lacking, leading to management and performance issues that cause inefficient project delivery.

1.4 Thesis Statement

By comparing actual data from real-world projects, this study will assess how the implementation of agile methodologies on heavy-civil construction projects influence issues relating to the Key Performance Indicators (KPI) of cost, quality, schedule, and safety, thereby determining if the implementation of agile methodologies results in improved project efficiency and delivery, as suggested by researchers who have published studies on the subject.

1.5 Research Objectives

The objective of this research is to show the impact of using agile methodologies in heavy-civil construction using actual project data. This will be done through the analysis of the Key Performance Indicators (KPI) in order to evaluate which, if any, actually realized improvement by utilizing said methods, identifying any differences that were statistically significant, and showing the impact they had on the overall project data. Most researchers suggest there will be improvements across the board and this study will serve to prove that theory. (Mendez, 2018).

1.6 Research Questions and Hypotheses

This research is focused on how agile methodologies affect real-world construction projects based on those Key Performance Indicators found in the research (Cost, Schedule, Quality, and Safety).

RQ1: Will the implementation of agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects reduce costs associated with variations or changes?

H_1: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will reduce costs associated with variations or changes.

H_0: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will not reduce costs associated with variations or changes.

RQ2: Will the implementation of agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects reduce costs associated with schedule delays?

H_1: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will reduce costs associated with schedule delays versus waterfall management methods.

H_0: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will not reduce costs associated with schedule delays versus waterfall management methods.

RQ3: Will the implementation of agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects reduce costs associated with quality rework versus waterfall management methods?

H_1: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will reduce costs associated with quality rework versus waterfall management methods.

H_0: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will not reduce costs associated with quality rework versus waterfall management methods.

RQ4: Will the implementation of agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects reduce costs associated with lost-time safety incidents versus waterfall management methods?

H_1: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will reduce costs associated with lost-time safety incidents.

H_0: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will not reduce costs associated with lost-time safety incidents.

RQ5: Will the implementation of agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects result in a better Project Success Index (PSI)?

H_1: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will result in a better Project Success Index (PSI).

H_0: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will not result in a better Project Success Index (PSI).

RQ6: Will the implementation of agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects result in a better Project Performance Value (PPV)?

H_1: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will result in a better Project Performance Value (PPV).

H_0: Applying agile methodologies instead of using waterfall management methods on heavy-civil bridge construction projects will not result in a better Project Performance Value (PPV).

RQ7: Does the Project Performance Value (PPV) result in statistically similar scoring as the Project Success Index (PSI)?

H_1: Comparing the Project Performance Value (PPV) to the Project Success Index (PSI) does not result in statistically similar scoring values.

H_0: Comparing the Project Performance Value (PPV) to the Project Success Index (PSI) results in statistically similar scoring values.

1.7 Scope of Research

The scope of this research was to focus on those journals and publications that concentrated on methods used to measure a construction project's success, to determine the Key Point Indicators used as measureable variables, to identify agile methods best-suited for construction projects, and to collect information available where agile methods were utilized on construction projects. Next, a considerable amount of time was spent researching and collecting actual project data, as provided by contractors and professionals in the field who were involved with the projects first-hand. Every effort was made to collect data from similar projects that focused on bridge and highway improvement projects with contract values at or about $20M. All projects collected and analyzed fell within these guidelines. Contractor names and project identities have been "sanitized" to protect proprietary interests.

1.8 Research Limitations

The limitations of this study are associated with data availability and the sources used for the data collected. This study assumes that the data providers are giving legitimate information to be used in the study, but cannot control what is given. Overall, all data collected seems to be reasonable, so this limitation is not likely. There could be inherent bias due to the fact that the select data used is a snapshot of typical projects and its source was limited to several companies who practice in the areas of interest. Assuming that they represent all companies and all projects world-wide could be inaccurate or unrealistic.

1.9 Organization of Praxis

The remainder of this study reviews research and literature regarding the use of agile and waterfall methods in construction and the outcomes of such projects. Chapter 3 presents the methodologies, research, data collection, and analysis methods used to best represent the data in hand. Chapter 4 presents the results of the research and the data analysis outcome. Chapter 5 provides the conclusions of the study based on the findings and presents recommendations for future work. Figure 1-5. *"Praxis Organization"* illustrates the organization of the praxis, detailing the chapters, and what they will cover.

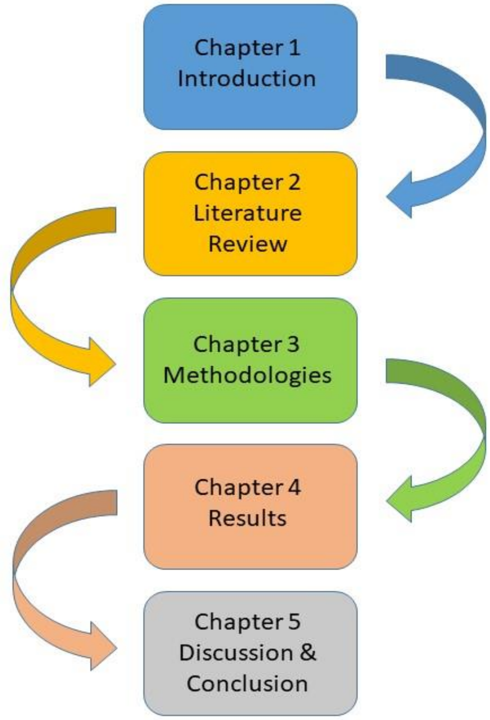

Figure 1-5. Praxis Organization

Chapter 2—Literature Review

"Plans are of little importance, but planning is essential."

- Winston Churchill

2.1 Introduction

The purpose of this study was to focus on how the implementation of agile methodologies in the field of heavy-civil construction can affect a project's outcome and to evaluate the existing research beliefs that were based on surveys and interviews versus using real-world project data. The first part of this research was to gain an understanding of where the construction industry is with respect to agile implementation, what studies have been performed to date, and what agile methodologies have been determined to be best-suited in the field of construction. Next, the focus turned to identifying what Key Performance Indicators have been established in order to accurately "score" a construction project for performance and to find scoring methods used in the field of construction to prove a project's success or failure. Having solid research journal sources to establish these foundational starting points was imperative in order to evaluate real-world data from construction projects that used agile methodologies for comparison to those that used traditional approaches.

2.2 Agile Project Management and Methods Best-Suited for Construction

Although some aspects of the agile methodologies with respect to project management have been in existence for decades, the concept really wasn't defined until the "Manifesto for Agile Software Development" (Beck et al, 2001) was published. Agile Project Management is defined by the "Manifesto" and it is actually a set of rules that define the agile approach. The manifesto is:

“We are uncovering better ways of developing software by doing it and helping others do it. Through this work we have come to value:

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

That is, while there is value in the items on the right, we value the items on the left more.” (Beck et al, 2001).

As presented, the authors suggest that the agile project management approach enhances existing management practices, leading the way to a better end product. Although the primary focus of agile dealt with the software development industry, many believe that these practices can also be applied to other industries; in particular, the heavy-civil construction field.

Defining the values of the Agile Manifesto, when discussing “Individuals and Interactions over Processes and Tool”, the authors mean that the individuals on the team, by working closely together, carry the responsibilities for developing and improving the processes as the project proceeds. (Johansson, 2012) Of note however, the second item in the manifesto, “Working Software over Comprehensive Documentation”, is not a practical application for the construction industry. All ownership organizations and public entities will require and maintain comprehensive documentation at some level. Additionally, for insurance and legal purposes, contractors are normally required to maintain documentation and records in-house for 5 years or more of past project data. In the past, this amounted to a great deal of handling of hard paper records, but with the advent of large-scale database technologies, records are much easier to store and maintain. Most projects are moving in the direction of the cloud or other database platforms. Regarding "Customer Collaboration over Contract Negotiation", the authors point out that good relationships between contractors and owners go much further than poor ones and working together will result in the best end product. The most important aspect of agile is the ability to respond quickly to issues and make changes as the process is on-going. This is what the fourth aspect, "Responding to Change over Following a Plan", indicates.

Of the agile methodologies available, many identify the scrum, sprints, and functional teams as being the best-suited for construction. In the studies of Ilieva et al. (2004), Svensson & Host (2005), Sillitti et al. (2005), Mann & Maurer (2005), they reported that the adoption of scrum methodology helps to simplify communication with the rest of the company, aids in the development of professional and interpersonal skills of staff, leads to a reduction of cost overruns, provides a more flexible and objective documentation, and maintains a more satisfying relationship with the client. Clearly, by implementing the scrum, the company builds stronger employee relationships and task-focused, functional teams.

By providing the individual employees with the opportunity to join specific functional teams, they are given a chance to take ownership of the process and thereby become a more engaged team member. Per Moreira (2013), "Employee engagement focuses on empowering employees so they can self-organize into teams and can own and be a part of the decision-making process at their own level…in scrum, you would use a sprint to develop a batch of work for these teams to assume responsibility for and be charged with the full task from start to finish." (p. 20).

As is with most endeavors, the ultimate goal of any project is to be fiscally successful. Moreira (2013) reminds us that the "The ultimate business benefit of going agile is that it can make the company more money. If you are truly committed to empowering your employees, then you will provide a work environment where they feel ownership of the work and can make their own decisions, and they will be more motivated to activate their brainpower, improving morale and increasing the likelihood that they will go the extra mile to create a quality product." (p.15). If empowering the employees as described results in better efficiency, then companies should by all means implement the systems that will lead to said empowerment. Overall, those construction projects that implement the scrum, sprints, and functional teams have the best chance for improved efficiency and project delivery. (Streule et al, 2016).

For this research, comparable projects (bridge and highway improvements valued at approximately $20M) were collected from contractors whose project managers introduced practices very similar to the scrum. The contractors held meetings, calling them "Resets" or "Revolvers" or "Updates", that were short, daily meetings attended by leadership and functional teams where tasks were assigned (sprints) with specific deadlines, while future meetings were the forum for feedback and oversight. In most cases, teams were broken down to a team leader and several people were assigned to assist in completing the allocated tasks. Team members normally included a manager, several engineers and/or superintendents, and administrative staff. By working as a team on a particular area of focus such as "Minor Structures" or "Utilities" or "Earthwork and

Paving", they covered all aspects of their areas such as processes, public notification, permits, submittals, traffic control, subcontractor coordination, material acquisition, equipment rental, inspection, testing, and scheduling work crews and were left to perform on their own outside of the scrums. Continual guidance and oversight was provided by upper management at the scrums and issues were handled proactively. The ultimate goal in these cases was to empower the employees in order for them to take ownership of their portions of the project and be more focused on the tasks at hand.

Part of the advantage of these meetings is described by Owen and Koskela (2006) as, "Working practices focus on frequent, sustainable iterative deliveries by facilitated multi-functional, self-organizing intercommunicative teams. Scrum and other agile methodologies add to those overall foci by prescribing numbers for the optimum team size (typically 5 to 20) and iteration periods (typically around 30 days, although varying widely)."(p. 23). On these actual projects, the team sizes did vary depending on the task at hand. In some cases drafters and temporary design engineers were part of the team, while others focused more on administrative, scheduling, and coordination-skilled team members.

In most of the projects sampled using agile management practices, the managers indicated that the processes, functional teams, and sprint tasks changed as the project progressed and that their functional teams were able to adapt more easily due to the daily scrums and the more detail-focused approach that comes with the agile management methodologies. The results provided by these project managers, who utilized the agile methodologies and allowed access to their project information for this research, were of measured success. Success that proved, at least internally, that when using these practices on their projects, they have a better chance for success with their application.

2.3 The Agile Research Gap in Construction

Most of the research that was found relating to agile management methods utilized in construction focused on interviews and survey questionnaires conducted with project professionals in the field of construction. These project professionals presented their assessment and opinions of how the implementation of the agile management methodologies could positively impact their projects, but rarely with any real-world application or citing for reference. "Real-World", in this case, meaning actual project managers and staff that measured key performance indicators from projects they managed using agile management methods and providing actual performance data for analysis taken from these agile-managed projects. The agile project data collected for this study was from projects that were managed using agile methods for the completion of the projects.

As F. Ribeiro (2010) explained, "Despite the amount of research work on agile concepts and the methods proposed by several authors, there is a striking absence of real applications of those concepts and models in the construction industry. Most of the publications highlight the theoretical aspects of agility without relating to specific real-world organizational environments." (p. 167). In his study, F. Ribeiro himself surveyed 12 construction company leaders or project engineers to gain knowledge and insight with respect to their beliefs on the various aspects of agile methods and those that they believed would be best implemented in the field of construction. Similarly, Ekstrom and Petterson (2016) studied the possibilities of the application of agile methods in construction by interviewing 12 professionals in the construction project management field. They also identified there to be anticipated positive gains in the construction industry, but did so without any real data, just their opinions. One of their future research topics was identified as that of studying real-world cases for better performance understanding.

Among those agile management methods identified as most prevalent by F. Ribeiro (2010), as well as Streule et al (2016), were the introduction of the scrum, use of sprints, and the forming of functional teams. Both of the authors also clearly identified the lack of data from real-world application of the agile methods identified in past research studies and further cited the utilization and resultant data would be of future industry value. A shared opinion by both authors also identified their belief that a larger data collection from projects that utilized agile methods compared to those that did not would be of significant value and contribution to the subject matter.

An example of survey-based research includes Fernandez and Fernandez (2008), who recognized that past research had identified that the introduction and implementation of agile methods in construction was likely to produce considerable improvements in project delivery and that more research should be performed with respect to the application of agile methods outside the scope of software design and production. Their belief was based on survey research and not on actual project data. Another by Owen (2006) also stated “Despite all these construction culture problems, the authors believe that there is room for use of Agile Project Management in construction on the site level, at least for planning, when managers can respond quickly to any change that might occur in the scope of the project.” (p. 17). In both of these cases, there are clear indications that the authors support the introduction of agile methods in construction and that they anticipate a measureable improvement in overall project efficiency and performance due to the implementation. They do so based on the opinion of themselves and others and not on actual data or project results.

Research engineer Johansson (2012) described the data used in a study on the introduction of agile methodologies to construction as “In the making of this thesis both primary and secondary data has been used. The primary data being results from the case study and the interviews conducted and the secondary data consisting of literature reviews and knowledge gained from scientific reports.” (p. 5). Further, in an effort to show how the agile management methods can benefit construction, Mostafa, S. et Al (2016) conducted their entire study on the available research and simply provided a Systematic Literature Review (SLR) to show how past studies have approached the subject, using no real-world data or project information. In another study, Mohammed and Jasim (2018) built their research and conclusions on how the methods found in the agile manifesto can be applied in construction based entirely on survey questionnaires received from 40 engineers in the construction industry. Clearly, these examples of agile methodologies in construction focus solely on questionnaires and not on any real-world project data. Yet again, more examples of available data being gathered through survey or past research, but not with actual performance data collected from project results.

Further research yielded several journal papers suggesting the study of more real-world projects could serve to demonstrate that there were indeed gains to be had by using agile in construction and that future studies should focus on this aspect. As indicated by Mendez (2018), “The primary limitation of this study was that it tested the guideline in only a single case study." (p. 77). Another research paper identified that agile tools, methods, and processes add considerable value to construction projects (Stracusser, 2015), but only considered 2 construction projects in the study. A study on the introduction of agile management methods for a project in Poland was conducted on one project, clearly not looking at large-scale sources of data over multiple projects. (Nowotarski and Paslowski, 2016). These real projects definitely indicated improvements and they are good examples of the successful implementation of agile methods, but gaining the knowledge of agile success on a much larger scale is needed if the industry will see utilization on a large-scale basis. P. Ribeiro (2013) simply stated "It would also be useful to enlarge the sample of companies surveyed in order to reinforce the obtained results." (p. 607), when discussing the success of projects.

Per F. Ribeiro (2010), "It is assessed that agile methods offer considerable potential for application in construction and that there are significant hurdles to its adoption in the actual phase. Should these be overcome, agile methods offer benefits well beyond any individual company." (p. 161). It is apparent that these sources all believe that agile methods, when introduced to construction on a large scale, would result in significant improvement in efficiency and delivery across the industry. They also recognize that full-scale implementation is not going to be an easy process due to various obstacles such as project-type, scope, and personnel to name a few. If the industry can adapt and overcome its obstacles, then the survey and questionnaire methods of research and data collection and those actual project data witness samples of success can be linked. This research aims to do that: link the predictions provided via interview and questionnaire-based research to the successes witnessed using real-world data performance.

2.4 Key Performance Indicators

The Key Performance Indicators (KPI) are those that are identified through the research as most commonly used to determine the success of a project. Although they can differ from the point of view of those evaluating the project, this study focused on those considered of highest value from the contractor's point of view. Per Chan (2004), "Owners, designers, consultants, contractors, as well as sub-contractors have their own project objectives and criteria for measuring success." (p. 204). Examples of other points of view could include the owner or the architect, where an owner might be more focused on public convenience as being a success factor or an architect may look at aesthetics as being an important measure, a contractor may not consider these elements to be as important. For the purposes of this study, the Key Performance Indicators (KPI) have been identified and summarized in the form of individual costs by each KPI to the contractor and illustrated in *Figure 2-1*. Key Performance Indicators (KPI's).

Identifying the KPI's, Chan (2004) writes "Time, cost, and quality are the basic criteria to project success, and they are identified and discussed in almost every article on project success" (p. 205). In addition to this, Chan (2004) also identifies safety as a KPI that needs to be considered by anyone who would be responsible for issues associated with it. Although their paper is more focused on the pre-construction phase of a project, Haponava and Al-Jibouri (2008) recognized that cost, time, and quality were of great importance, and although they referred to another KPI as risk management, part of this clearly includes the safety of the project as a whole. Expenses associated with all four of these KPI's are typically borne by the contractor and these are normally considered the most important measures on any construction project.

Other potential KPI's considered were environmental impact, public convenience, team relations, and technology. The environmental impact is typically not a big consideration from the point of view of the contractor other than doing what can be done to avoid fines or violations associated with the various environmental permits. Costs are typically negligible outside of the normal site tasks associated with such work. Public convenience is mostly associated with traffic, but can include items such as noise control, dust control, damage to surrounding facilities or roadways, and private property incursions. As with environmental concerns, issues associated with public convenience are typically minimal and efforts outside of the normally bid scope of work are rarely encountered. Team relations refers to the contractor's leadership team and the project ownership team and their ability to get along. On most construction projects, a practice called "Partnering" is included as an item in the bid and its implementation usually takes care of any issues relating to this subject. Costs are rarely incurred outside of what is anticipated for partnering. Lastly, technology on a construction site might include a computer or cell phone. The size of the project does affect the amount of technology with respect to data storage and management, but anything needed is typically identified at bid time and there are rarely issues with performance.

Subsequently, the four KPI's of Cost, Schedule, Quality, and Safety are most commonly identified and what this study focuses on. Figure 2-1. *"Key Performance Indicators (KPI's)"* illustrates the Key Performance Indicators as described.

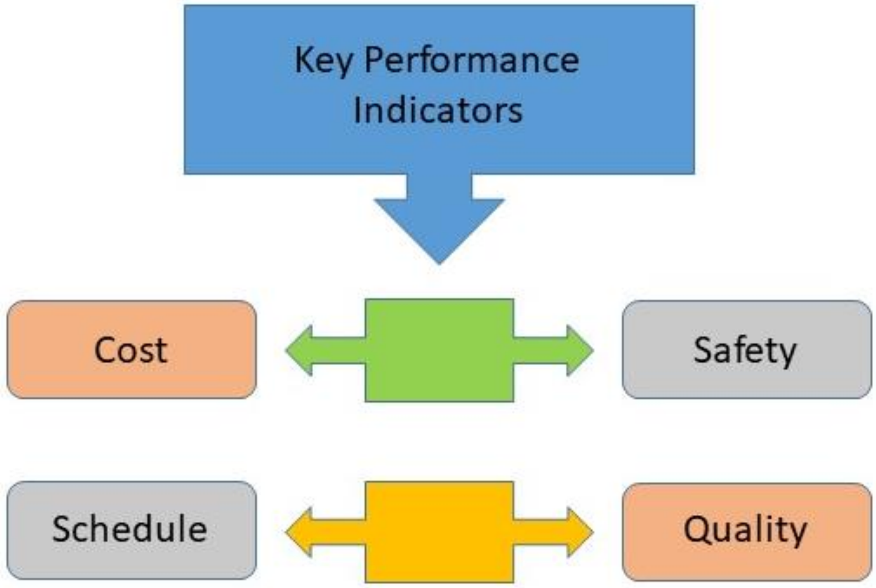

Figure 2-1. Key Performance Indicators (KPI's)

2.4.1 Cost

Cost, as identified in this study, are all of those costs associated with unforeseen circumstances or variations typically encountered in construction. These can include material price fluctuations, equipment availability issues, delivery delays, material performance issues, manpower shortcomings, and any other additional, unanticipated costs that were not included in the original bid process. Legal costs should also be assigned to this indicator as they are normally unforeseen and can negatively affect a job's performance. As defined by Chan (2004), costs are "any costs that arise from variations or modifications during the construction period and the costs arising from legal claims, such as litigation and arbitration." (p. 209).

Although efforts are made to minimize additional costs, some issues are out of the control of the contractor and can't be avoided. These costs do not include anything to do with schedule delays, quality rework, or safety incidents.

2.4.2 Schedule

Costs associated with schedule relate to weather delays, access delays, extended activity durations, third-party delays, and owner interference. A simplified illustration is seen in Figure 2-2. *"Schedule"* showing the simplified major steps on any project. Although weather delays are not typically chargeable work days, costs are still encountered regarding the need to maintain work areas, office space, personnel and staff positions, etc. Access delays can include Right-of-Way delays, permit delays, and third-party interference.

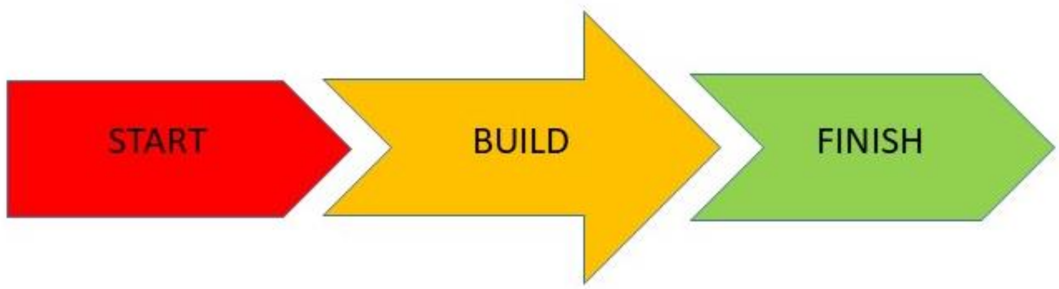

Figure 2-2. Schedule

All of these schedule issues prevent the contractor from gaining access to the project and completing the work in a timely manner. Third-party delays can include utilities, local agencies, or subcontractors. Owner interference or poor relations can cause schedule delays in how stringent they are in meeting all project requirements. It is difficult to predict what type of ownership group will be involved, but contractors typically do all they can to keep positive working relations and thus an easier build, void of constant interference and distraction.

2.4.3 Quality

Although the area of quality can include multiple areas of focus, this study considers it to be costs associated with rework or repair on substandard work where the contract specifications were not met. As illustrated in Figure 2-3. “Quality”, we see the quality process as a cyclical one that is constantly trying to improve and produce a better product, however there are cases where issues arise that can’t be avoided. These issues can include completed work that is required to be removed and redone or work that needs cosmetic repair, not anticipated in the original bid. These types of issues are common on projects but do not occur on every one. Quality issues can result in significant cost increases and associated delays to the project and efforts are typically made to minimize mistakes.

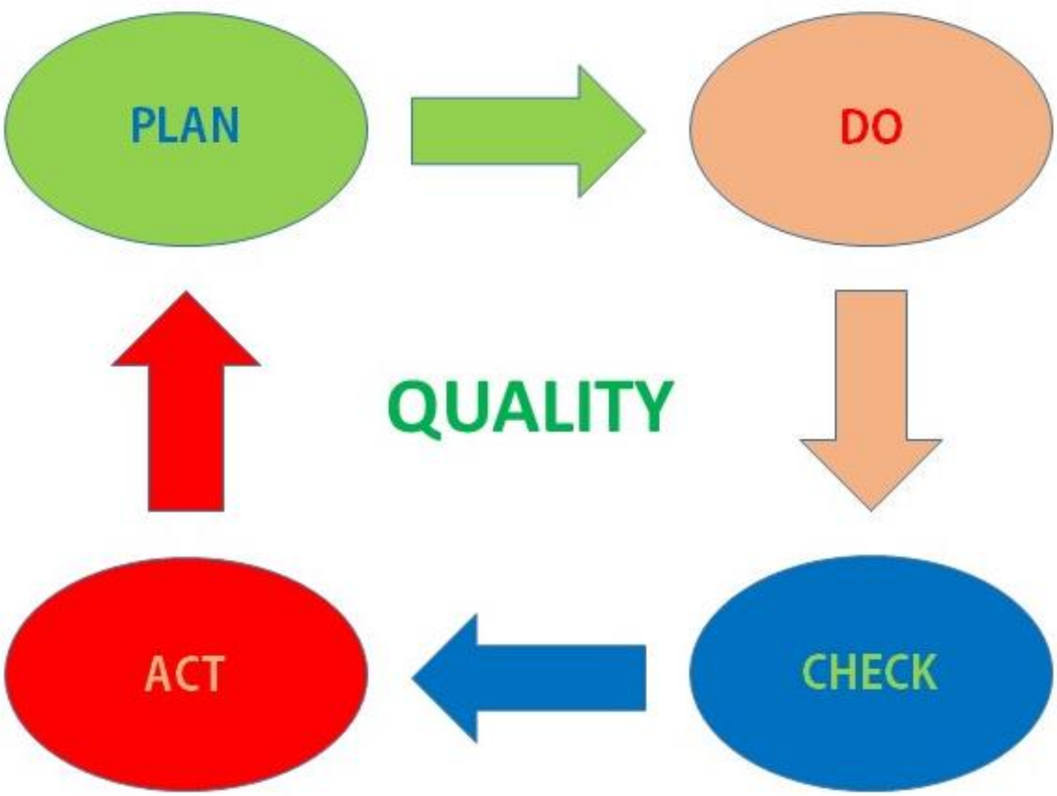

Figure 2-3. Quality

2.4.4 Safety

Costs associated with safety incidents are considered a major factor on a construction project. Not only are there significant financial impacts, but there can also be life-changing repercussions. On top of that, there could be insurance and legal issues that last for years. For this study, contractors consider safety incidents as those that result in "Lost-Time", meaning the individual or individuals missed work time due to an injury. This normally entails a hospital visit and reduced-impact workloads for the employee for an extended period of time with full-pay. Additionally, it can include paid time off for healing purposes, therapy, workers compensation, permanent disability, and in the worst cases, death. Most contractors have extensive safety programs and regular diligence is an expected practice by all people on site.

2.5 Scoring Methods

This section will focus on what scoring methods are already available to the construction field and also introduce a new technique that will simplify the existing methods, giving interested parties an approach to scoring that is simply the direct costs to the project due to the established KPI's. Once the KPI's were established, the focus of the research shifted to choosing scoring methods already developed and available for use on various typical construction projects. Most scoring methods encountered focused on similar KPI's as those previously identified and weighted them per opinion surveys of professionals in the field. One such method found was created by Khosravi and Afshari (2011), which established a Project Success Index (PSI) based on their own developed KPI's.

The KPI's identified in their paper were:

1. Project Cost Performance (PCP)
2. Project Time Performance (PTP)
3. Project Quality Performance (PQP)
4. Project Health, Safety, and Environment (HSE) Performance (PHP)
5. Project Client Satisfaction (PCS)

The authors in this study sought the opinion of construction professionals who "...had long-term experience in execution of construction projects ranging from the middle managers to the project managers..." (Khosravi and Afshari, 2001). Surveys were issued in order for each individual to assign a score that represented their opinion of importance regarding the KPI's and, once complete, they were returned for analysis. As received, the authors summarized and combined the answers given and developed an equation that gave a weighted constant to each of the Key Performance Indicator variables as follows:

$$PSI = 0.209PTP + 0.233PCP + 0.199PQP + 0.173PHP + 0.186PCS \qquad (1)$$

The intent of this created formula was for the user to identify the units and input the values accordingly, therefore, if all that was sought was cost value, as in our case for example, then all variables would be input in monetary value and evaluated as such. Another approach could be time associated with each KPI. This could be a tool used to see how the construction schedule was allocated or where problem areas existed. Another option could be for the user to focus only on client satisfaction, adjusting the project variables in order to score based on the client's point of view. There are multiple ways this equation could be used to evaluate any given project.

Considering the Key Performance Indicators selected for this study, the Project Success Index formula above was adjusted to the following:

$$PSI = 0.257PTP + 0.286PCP + 0.244PQP + 0.213PHP \quad (2)$$

The reason for this adjustment is that Project Client Satisfaction is not something easily measured in monetary value, unless there are specific performance target and reward conditions built into the contract. This type of incentive program is not the norm and therefore, was not included for the purposes of this study. In fact, none of the projects recorded for this study had any incentive clauses built in to their contracts other than the normal schedule limitations that serve only to penalize missed deadlines, rather than reward for early completion. The 0.186 value assigned to the Project Client Satisfaction variable in the referenced paper was proportionally distributed over the other four variables based on their share of the remaining total. All of this is summarized in Table 2-1. *"Updated Constants for PSI"* as follows:

Value	PTP	PCP	PQP	PHP	Sum
Original Constant (OC)	0.209	0.233	0.199	0.173	0.814
% of Sum of OC	0.257	0.286	0.244	0.213	1.000
Share of PCS Value	0.048	0.053	0.045	0.040	0.186
New Total	0.257	0.286	0.244	0.213	1.000

Table 2-1. Updated Constants for PSI

Where; Original Constant (OC) = the constants assigned to the original KPI's.

% Sum of OC = OC / Sum of OC

Share of PCS Value = % Sum of OC x 0.186

New Total = OC + Share of PCS Value

As a result of adjusting the PSI study above, the four remaining Key Performance Indicators selected for this study were identified and correlated to this study as follows:

Project Cost Performance (PCP) = Cost

Project Time Performance (PTP) = Schedule

Project Quality Performance (PQP) = Quality

Project HSE Performance (PHP) = Safety

Taking this research further and combining it with personal practical experience, a different scoring approach was developed that allows the user to more clearly identify the recorded success scores with actual KPI costs. While the Project Success Index (PSI) scoring system does have value in that it gives a final score based on weighted KPI's for comparison to other PSI's, it does not provide a direct cost overall associated with the KPI's and that is the goal for this project. Contractors want to know where all of their costs are being incurred. The proposed system will reveal a score that is not only a scoring value, but it also directly correlates to cost. This is called the Project Performance Value (PPV).

With the Project Performance Value method of scoring, all of the original Key Performance Indicators are used (Cost, Schedule, Quality, and Safety) and costs associated with each are taken directly from the project data, as they were under the Project Success Index method. The difference is where the Project Success Index method uses weighted coefficients to establish an importance level for each Key Performance Indicator, the Project Performance method develops an actual cost total for the combined costs of each KPI.

For example, using the following hypothetical values for a typical project found in Table 2-2. *"Sample KPI Values"*, where K = One Thousand, we find:

KEY PERFORMANCE INDICATOR	VALUE
COST	$100K
SCHEDULE	$60K
QUALITY	$40K
SAFETY	$30K

Table 2-2. Sample KPI Values

The Project Success Index (PSI) method of scoring the project would be:

PSI = 0.257PTP + 0.286PCP + 0.244PQP + 0.213PHP

PSI = (0.257 X 60) + (0.286 X 100) + (0.244 X 40) + (0.213 X 30)

PSI = 15.42 + 28.6 + 9.76 + 6.39

PSI = 60.2

The Project Success Index (PSI) yields a score of 60.2 that can be compared to other project data and ranked based on upper and lower boundaries determined by the evaluator.

The Project Performance Value (PPV) method of scoring the project would be:

PPV = Cost + Schedule + Quality + Safety (3)

PPV = 100 + 60 + 40 + 30

PPV = 230 = $230K

Using the Project Performance Value method, we simply add all of the additional costs recorded for an individual project and get a real dollar amount ($230,000.00) that accurately reflects the cost added by the Key Performance Indicators that were not anticipated at the time of bid. There is a definite benefit in using this method as there is no need for conversion or understanding what each Project Performance Value (PPV) indicates; it is simply the costs that could potentially be saved. On a project with a contract value of $10M, $230,000 represents nearly one quarter of the anticipated profit that is lost. No contractor wants this kind of impact and anything that can be done to prevent the loss would be considered. In all cases, the lower the PPV score (cost), the better.

Moving forward, rather than the values used above (i.e. PCP, PTP, etc) being hypothetical values as found in other research studies, the values in this study will be taken from actual projects that used the waterfall management approach, as well as those that used agile methods of project management for comparison. This will be detailed in Chapter 4.

2.6 Summary

As discussed, past researchers have predicted that the introduction of agile methodologies to construction will result in better project efficiency and delivery. There are also those who believe that further research should be accomplished with real world data to prove these beliefs. Stracusser (2015) wrote that "It is recommended that some of the principles of agile be evaluated for use in other industries/projects and that management make investments in non-core training for their personnel." (p. 1). Similarly, F. Ribeiro (2010) stated "It is assessed that agile methods offer considerable potential for application in construction. Small, multi-disciplinary project teams formed with the most skilled, empowered and highly motivated people and short, frequent meetings with all team members can help to increase efficiency." (p. 175) and finally, Mendez (2018) determined that "Based on the case study and comparative analysis to other projects carried out using non-agile methods, there were clear gains to be had in terms of quality, productivity, and safety.” (p. 73).

Considering these journal-sourced theories, along with those discussed throughout this chapter, there is a need to study the results of using agile management methods in heavy-civil construction from real data. Further, there is a gap identified from the literature researched with respect to the analysis of real-world agile data and its comparison to normally-managed projects. As such, this study has collected data from 40 projects that used the waterfall (linear) approach to project management, as well as one that has gathered data from 40 projects that utilized the agile methods discussed previously. The remaining chapters will provide the data and its analysis, along with conclusion and recommendations for future studies.

Chapter 3—Methodology

"Agility is the ability to adapt and respond to change... agile organizations view change as an opportunity, not a threat."

- Jim Highsmith

3.1 Introduction

The goal of this study is to evaluate how the application of agile methods in heavy-civil construction affects project performance with respect to cost to the contractor. In order to accomplish this, significant time was spent collecting actual project data from multiple projects, as provided by several contractors in the industry. These contractors utilized agile methods in their management approach or they used the more traditional waterfall approach. With this project data, costs to the contractor were developed for analysis. Costs considered were those relating to unfunded contract variations, schedule delays, quality rework, and safety incidents. All project information, locations, and contractor identity has been withheld for proprietary purposes.

3.2 Research Methodology

The research methodology for this study was both qualitative and quantitative. The qualitative aspect included researching and determining what has been done to date with respect to scoring construction projects, how the waterfall method of project management has been implemented in construction, how agile methodologies have been applied in construction, what have been the best agile methods used (in the opinion of past researchers and those in the field who have used them) in construction, and what gaps in the research exist for current and future studies.

The quantitative portion of this study focused on the potential project cost changes realized by using the traditional management approach of waterfall versus those that utilized agile methods. These cost variations were determined by actual project cost data, as collected from various contractors and project managers who currently practice in the industry. 40 projects from each type of management approach were collected and organized for statistical evaluation. Further details are discussed below.

3.3 Data Collection

The quantitative data collection phase of this study took place over a 6-month period where multiple contractors and project managers were contacted in order to collect pertinent contract information from actual projects completed to date. The contractor data for the waterfall projects came from 5 different contractors located both inside and outside of California, while the data collected for the agile management methods came from 4 different contract project managers who at the time worked for 3 different contractors in California and the East Coast. To narrow down this study, efforts were successfully made to gather project data that focused on bridge and highway work in order to accurately compare similar projects. Bridge and highway projects as defined for this study, were those that included at least one bridge construction, replacement, or repair along with highway paving or tie-in to get the project back in use by the public.

The first information collected had to do with all pertinent KPI costs encountered by those contractors and project managers who utilized the traditional, top-down/waterfall method of project management. Data from the waterfall projects was found to be abundant, and was quickly collected from multiple contractors who work in the field of heavy-civil construction. The next portion, which was much more difficult and time consuming, focused on data from projects where contractors and project managers implemented agile methodologies. Professional contacts were used to facilitate data collection.

During the data organization and evaluation stage of this study, the project costs associated with variations, schedule delays, quality rework, and safety (KPI's) were separated so that they could be evaluated and summarized for analysis. Once summarized, the PSI scoring system discussed in Section 2.6 was used to score the projects. Additionally, the new PPV scoring method also discussed in Section 2.6 was used to score the projects. After adjusting the PSI scores to be compatible with the PPV scores, the PPV and PSI values were compared for statistical differences. The PPV for both agile and waterfall methods were compared to each other for statistical difference as well, as were the PSI's.

Per Table 3-1. *"Sample Cost and Schedule Data"*, a sample of a specific project's data is presented for information as follows:

Project Title	**Bid Information**					**End of Project Information**				
	Bid(M)	**BCost (M)**	**BCost (%)**	**BP (M)**	**BWD**	**Final (M)**	**FCost (M)**	**FCost (%)**	**FP (M)**	**FWD**
Mill Bridge Replacement	$22.05	$20.07	91.0%	$1.98	200	$22.75	$20.82	91.5%	$1.93	223

Table 3-1. Sample Cost and Schedule Data

The bid information presents the following:

Bid (M): Total Bid Amount in Millions of Dollars

BCost (M): Direct and Indirect Costs as Projected at Bid Time in

Millions of Dollars

BCost (%): Direct plus Indirect Costs as Projected at Bid Time as a Percentage of Total Bid

BP (M): Profit as Projected at Bid Time in Millions of Dollars

BWD: Working Days as Projected at Bid Time

Final (M): Final Contract Value at End of Project in Millions of Dollars

FCost (M): Final Direct and Indirect Costs as Realized in Millions of Dollars

FCost (%): Final Direct plus Indirect Costs as Realized as a Percentage of Final Contract Value.

FP (M): Profit as Realized in Millions of Dollars

FWD: Final Working Days as Realized at End of Project

In addition to the information presented in Table 3-1. *"Sample Cost and Schedule Data"*, more information was also collected as shown in Table 3-2. *"Sample Quality and Safety Incident Data"* with respect to quality and safety.

Project Title	**Quality Incidents**			**Safety Incidents**		
	Count	**Cost ($)**	**Days**	**Total Incidents**	**Lost Time (Each)**	**Time Lost (Days)**
Mill Bridge Replacement	12	$78,900.00	20	5	0	0

Table 3-2. Sample Quality and Safety Incident Data

The variables are defined as:

Count: Number of Quality Incidents

Cost ($): Cost of Identified Quality Incidents

Days: Effect of Quality Incidents in Time

Total: Total Amount of Safety Incidents

Lost Time: Number of Lost-Time Safety Incidents

Time Lost: Amount of Days Lost by an Employee(s)

Continuing on with the analysis, the next step was to determine the realized final cost to the contractor for the project and the realized profit based on the final contract value. With this information, we can determine where the project finished compared to how it was bid and what, if any, costs were incurred due to changes. Looking at Table 3-3. *"Final Cost and Profit Data"*, we see the following values for the hypothetical case:

Project Title	**C_{Delta} ($M)**	**P_{Delta} ($M)**	**$C_{TProject}$ ($M)**
Mill Bridge Replacement	$ 0.075	$ (0.005)	$ 0.080

Table 3-3. "Final Cost and Profit Data"

C_{Delta} ($M) = FCost ($M) – BCost ($M) in millions ($) is the change in cost to the contractor from the projected cost at the time of bid to the actual cost at the end of the project.

P_{Delta} ($M) = FP ($M) – FB ($M) in millions ($) is the Change in Profit from the anticipated profit at the time of bid to the actual profit at the end of the project.

$C_{TProject}$ (M) = C_{Delta} (M) - P_{Delta} (M) is the Total Added Costs to the project for variations or changes that were not anticipated.

In the case of this project, the cost to complete the project went up by $75,000.00 while the anticipated profit decreased by $5,000.00, therefore yielding a total added cost due to variation of $80,000.00.

Next, summarizing all of the issues that lead to the unanticipated costs is detailed in Table 3-4. *"PPV Summary"* found below:

Project Title	C_{Sched} (M)	C_{Qual} (M)	C_{safe} (M)	$C_{TProject}$ (M)	PPV
Mill Bridge Replacement	$ 0.230	$ 0.079	$ 0.00	$0.080	0.389

Table 3-4. "PPV Summary"

C_{Sched} (M) = (FWD – BWD) x $10,000 per day. This amount is also referred to as Liquidated Damages and they are the owner's way of ensuring that the project is finished on time. In this case, they did not finish on time and incurred a significant penalty. The penalty of $10,000 can vary by the project, but this value is typical for the size of projects under consideration per typical projects found on Caltrans projects.

C_{Qual} (M) = Actual Costs. Quality costs and associated negative consequences are tracked in most cases. In this case, there were 12 incidents that cost the contractor 20 working days and ultimately $79,000.00. This amount accounts for any added costs due schedule delays.

C_{safe} (M) = Time Lost (Days) x $1,200 per day. The $1,200.00 per day represents the wages that are still paid, workers compensation increases, medical costs, and costs associated with loss of manpower. This cost is derived from knowing what the typical union worker costs the contractor per 8-hour day. These are specific to the event, but on average and based on experience, we can expect the $1,200 per day cost.

$C_{TProject}$ (M) = C_{Delta} (M) - P_{Delta} (M) is the Total Added Costs to the project for variations or changes that were not anticipated. Increase in anticipated profit can help offset costs, but few contractors count on increases at the start of the project.

PPV = $C_{TProject}$ (M) + C_{Sched} (M) + C_{Qual} (M) + C_{safe} (M). This is one way of measuring a project's performance developed in this study. It can be used as a unit-less number or as a cost. Either way, the number value is the same.

In the hypothetical case presented in this chapter, we find that the project, which happens to be a waterfall-managed project, had added costs that were unanticipated in the amount of $389,000.00. This was a significant addition to the contract and any contractor would be looking for ways to improve. In context, these added costs negated nearly 20% of the anticipated profit. As will be shown in Chapter 4, for this study we see an average improvement using agile methodologies in the neighborhood of 40%. In this case, that would have amounted to a savings of $155,600.00.

Data from 40 projects that employed the waterfall approach and 40 projects that implemented agile methods were collected. The information sample presented in the tables shows the information as it was gathered from each project. From this information, all Key Performance Indicators, Project Success Indices, and Project Performance Values were evaluated and determined. Further analysis and study has been conducted and all information found with respect to the data is presented in the next chapter.

Chapter 4—Results

"Management is all about managing in the short term, while developing the plans for the long term."

- Jack Welch

4.1 Introduction

This chapter presents the collected data and evaluates it for both statistical significance and actual cost improvement when comparing agile project data with waterfall project data. Considering the data collected for both waterfall and agile projects and exhibited in Tables 4-2. *"Waterfall Project Bid Data"* through 4-11. *"Agile Variable Data and PSI"*, there were two approaches that were taken to analyze and present the information in logical form.

The first approach simply looked at the data as straight numerical values (costs) by KPI in order to compare the two types of projects. From this approach, average costs for each KPI can be seen and compared for actual cost difference between the two data sets. Table 4-1. *"Average Values and Analysis Summary"* summarizes these numerical values and reveals that there is improvement in all cases when agile methods were used.

Management	Cost	Schedule	Quality	Safety	PSI	PPV
Waterfall	$ 75,600.00	$ 89,300.00	$ 31,700.00	$ 18,500.00	0.0610	0.215
Agile	$ 72,100.00	$ 30,800.00	$ 12,600.00	$ 15,700.00	0.0398	0.131
Delta	$ 3,500.00	$ 58,500.00	$ 19,100.00	$ 2,800.00	0.0212	0.084

Table 4-1. Average Values and Analysis Summary

Proj. #	Bid(M)	BCost (M)	BCost (%)	BP(M)	BWD
1	$ 22.05	$ 20.07	91.0%	$ 1.98	200
2	$ 20.35	$ 18.58	91.3%	$ 1.77	185
3	$ 20.15	$ 17.93	89.0%	$ 2.22	180
4	$ 15.95	$ 14.51	91.0%	$ 1.44	145
5	$ 16.60	$ 15.36	92.5%	$ 1.25	150
6	$ 20.75	$ 19.09	92.0%	$ 1.66	140
7	$ 15.95	$ 14.12	88.5%	$ 1.83	220
8	$ 15.65	$ 14.32	91.5%	$ 1.33	180
9	$ 20.60	$ 18.81	91.3%	$ 1.79	190
10	$ 18.00	$ 16.47	91.5%	$ 1.53	180
11	$ 15.95	$ 14.83	93.0%	$ 1.12	145
12	$ 19.25	$ 17.67	91.8%	$ 1.58	140
13	$ 20.55	$ 18.29	89.0%	$ 2.26	205
14	$ 15.55	$ 14.43	92.8%	$ 1.12	150
15	$ 19.60	$ 18.03	92.0%	$ 1.57	175
16	$ 17.90	$ 16.74	93.5%	$ 1.16	185
17	$ 15.80	$ 14.50	91.8%	$ 1.30	120
18	$ 16.25	$ 15.08	92.8%	$ 1.17	150
19	$ 21.95	$ 19.93	90.8%	$ 2.02	195
20	$ 16.95	$ 15.73	92.8%	$ 1.22	170
21	$ 16.25	$ 15.03	92.5%	$ 1.22	160
22	$ 16.75	$ 15.49	92.5%	$ 1.26	160
23	$ 21.50	$ 19.57	91.0%	$ 1.94	210
24	$ 15.50	$ 14.23	91.8%	$ 1.27	170
25	$ 23.25	$ 20.69	89.0%	$ 2.56	210
26	$ 15.60	$ 14.51	93.0%	$ 1.09	160
27	$ 16.25	$ 14.87	91.5%	$ 1.38	180
28	$ 16.35	$ 15.17	92.8%	$ 1.18	160
29	$ 18.25	$ 16.79	92.0%	$ 1.46	185
30	$ 16.85	$ 15.22	90.3%	$ 1.63	150
31	$ 16.45	$ 15.13	92.0%	$ 1.32	165
32	$ 17.50	$ 15.93	91.0%	$ 1.58	170
33	$ 16.90	$ 15.21	90.0%	$ 1.69	160
34	$ 17.25	$ 15.44	89.5%	$ 1.81	160
35	$ 16.50	$ 15.18	92.0%	$ 1.32	175
36	$ 16.85	$ 15.50	92.0%	$ 1.35	180
37	$ 16.75	$ 15.21	90.8%	$ 1.54	145
38	$ 19.25	$ 17.52	91.0%	$ 1.73	190
39	$ 24.30	$ 22.60	93.0%	$ 1.70	215
40	$ 23.65	$ 21.99	93.0%	$ 1.66	220
Avg	**$ 18.19**	**$ 16.64**	**91.5%**	**$ 1.55**	**173.25**

Table 4-2. Waterfall Project Bid Data

Proj. #	Final (M)	FCost (M)	FCost (%)	FP(M)	FWD	C_{Delta} (M)	P_{Delta} (M)
1	$ 22.75	$ 20.82	91.5%	$ 1.93	223	$ 0.75	$ (0.05)
2	$ 21.55	$ 19.27	89.4%	$ 2.28	184	$ 0.69	$ 0.51
3	$ 21.30	$ 19.17	90.0%	$ 2.13	185	$ 1.24	$ (0.09)
4	$ 17.00	$ 15.51	91.3%	$ 1.49	164	$ 1.00	$ 0.05
5	$ 17.30	$ 15.95	92.2%	$ 1.35	176	$ 0.60	$ 0.10
6	$ 22.40	$ 21.06	94.0%	$ 1.34	144	$ 1.97	$ (0.32)
7	$ 16.80	$ 13.78	82.0%	$ 3.02	226	$ (0.34)	$ 1.19
8	$ 16.35	$ 15.12	92.5%	$ 1.23	192	$ 0.80	$ (0.10)
9	$ 21.10	$ 19.83	94.0%	$ 1.27	194	$ 1.03	$ (0.53)
10	$ 19.00	$ 17.96	94.5%	$ 1.05	169	$ 1.49	$ (0.48)
11	$ 17.05	$ 16.03	94.0%	$ 1.02	153	$ 1.19	$ (0.09)
12	$ 20.70	$ 19.56	94.5%	$ 1.14	148	$ 1.89	$ (0.44)
13	$ 21.95	$ 19.76	90.0%	$ 2.20	209	$ 1.47	$ (0.07)
14	$ 16.50	$ 15.39	93.3%	$ 1.11	163	$ 0.96	$ (0.01)
15	$ 21.00	$ 19.64	93.5%	$ 1.37	171	$ 1.60	$ (0.20)
16	$ 18.65	$ 17.39	93.3%	$ 1.26	189	$ 0.65	$ 0.10
17	$ 16.85	$ 16.01	95.0%	$ 0.84	132	$ 1.50	$ (0.45)
18	$ 17.15	$ 15.95	93.0%	$ 1.20	152	$ 0.87	$ 0.03
19	$ 23.25	$ 20.46	88.0%	$ 2.79	206	$ 0.53	$ 0.77
20	$ 17.60	$ 16.19	92.0%	$ 1.41	177	$ 0.46	$ 0.19
21	$ 17.05	$ 15.73	92.3%	$ 1.32	170	$ 0.70	$ 0.10
22	$ 18.00	$ 16.65	92.5%	$ 1.35	164	$ 1.16	$ 0.09
23	$ 22.60	$ 20.28	89.8%	$ 2.32	199	$ 0.72	$ 0.38
24	$ 16.85	$ 15.46	91.8%	$ 1.39	187	$ 1.23	$ 0.12
25	$ 23.50	$ 20.97	89.3%	$ 2.53	218	$ 0.28	$ (0.03)
26	$ 16.45	$ 15.30	93.0%	$ 1.15	181	$ 0.79	$ 0.06
27	$ 16.65	$ 15.23	91.5%	$ 1.42	184	$ 0.37	$ 0.03
28	$ 17.35	$ 16.05	92.5%	$ 1.30	156	$ 0.88	$ 0.12
29	$ 18.85	$ 17.25	91.5%	$ 1.60	191	$ 0.46	$ 0.14
30	$ 17.40	$ 15.83	91.0%	$ 1.57	156	$ 0.62	$ (0.07)
31	$ 16.90	$ 15.55	92.0%	$ 1.35	173	$ 0.41	$ 0.04
32	$ 17.90	$ 15.80	88.3%	$ 2.10	189	$ (0.13)	$ 0.53
33	$ 17.70	$ 15.89	89.8%	$ 1.81	167	$ 0.68	$ 0.12
34	$ 17.45	$ 15.18	87.0%	$ 2.27	183	$ (0.26)	$ 0.46
35	$ 17.45	$ 16.04	91.9%	$ 1.41	190	$ 0.86	$ 0.09
36	$ 17.40	$ 15.94	91.6%	$ 1.46	198	$ 0.44	$ 0.11
37	$ 17.10	$ 15.73	92.0%	$ 1.37	147	$ 0.52	$ (0.17)
38	$ 20.60	$ 18.77	91.1%	$ 1.83	179	$ 1.25	$ 0.10
39	$ 25.30	$ 23.28	92.0%	$ 2.02	234	$ 0.68	$ 0.32
40	$ 24.95	$ 23.08	92.5%	$ 1.87	222	$ 1.08	$ 0.22
Avg	**$ 19.09**	**$ 17.47**	**91.5%**	**$ 1.62**	**181.13**	**$ 0.827**	**$ 0.072**

Table 4-3. Waterfall Project Outcome Data

Proj. #	Quality Incidents			Safety Incidents		
	Count	Cost ($)	Days	Total	Lost Time	Time Lost
1	12	$ 78,900.00	20	5	0	0
2	1	$ 16,150.00	2	4	1	5.8
3	4	$ 20,550.00	11	4	0	0
4	1	$ 9,850.00	2	1	0	0
5	1	$ 109,800.00	24	4	1	5.8
6	0	$ -	0	3	0	0
7	4	$ 31,400.00	19	5	1	4.2
8	0	$ -	0	4	2	4.2
9	4	$ 94,600.00	3	5	0	0
10	0	$ -	0	0	0	0
11	5	$ 69,300.00	18	4	0	0
12	1	$ 41,200.00	21	3	0	0
13	3	$ 76,800.00	16	5	0	0
14	0	$ -	0	4	2	7.5
15	2	$ 36,700.00	8	4	1	7.5
16	0	$ -	0	4	0	0
17	8	$ 84,650.00	14	3	0	0
18	0	$ -	0	0	0	0
19	1	$ 24,850.00	4	5	0	0
20	0	$ -	0	4	0	0
21	4	$ 56,250.00	4	4	1	7.5
22	0	$ -	0	4	0	0
23	0	$ -	0	5	2	0
24	4	$ 109,900.00	17	4	0	0
25	1	$ 14,900.00	0	5	0	0
26	2	$ 41,750.00	10	4	0	0
27	0	$ -	0	4	0	0
28	3	$ 109,500.00	22	4	1	7.5
29	0	$ -	0	0	0	0
30	0	$ -	0	4	0	0
31	2	$ 45,200.00	9	4	0	0
32	3	$ 25,350.00	5	4	2	7.5
33	1	$ 34,500.00	13	4	0	0
34	2	$ 46,950.00	7	4	0	0
35	0	$ -	0	0	0	0
36	5	$ 39,900.00	8	5	0	0
37	0	$ -	0	3	0	0
38	0	$ -	0	4	0	0
39	2	$ 45,950.00	5	5	0	0
40	0	$ -	2	5	1	4.2
Avg	**1.90**	**$ 31,622.50**	**6.60**	**3.73**	**0.375**	**1.54**

Table 4-4. Waterfall Quality and Safety Data

Proj. #	$C_{TProject}$ (M)	C_{Sched} (M)	C_{Qual} (M)	C_{safe} (M)	C_{TSCQSF} (M)	Project Performance Value (PPV)
1	$ 0.080	$ 0.230	$ 0.079	$ -	$ 0.309	0.379
2	$ 0.018	$ -	$ 0.016	$ 0.070	$ 0.086	0.206
3	$ 0.133	$ 0.050	$ 0.021	$ -	$ 0.071	0.186
4	$ 0.095	$ 0.190	$ 0.010	$ -	$ 0.200	0.305
5	$ 0.050	$ 0.260	$ 0.110	$ 0.070	$ 0.440	0.509
6	$ 0.229	$ 0.040	$ -	$ -	$ 0.040	0.205
7	$ (0.153)	$ 0.060	$ 0.031	$ 0.050	$ 0.141	0.227
8	$ 0.090	$ 0.120	$ -	$ 0.050	$ 0.170	0.240
9	$ 0.156	$ 0.040	$ 0.095	$ -	$ 0.135	0.185
10	$ 0.197	$ -	$ -	$ -	$ -	0.100
11	$ 0.128	$ 0.080	$ 0.069	$ -	$ 0.149	0.259
12	$ 0.233	$ 0.080	$ 0.041	$ -	$ 0.121	0.266
13	$ 0.154	$ 0.040	$ 0.077	$ -	$ 0.117	0.257
14	$ 0.097	$ 0.130	$ -	$ 0.090	$ 0.220	0.315
15	$ 0.180	$ -	$ 0.037	$ 0.090	$ 0.127	0.267
16	$ 0.055	$ 0.040	$ -	$ -	$ 0.040	0.115
17	$ 0.195	$ 0.120	$ 0.085	$ -	$ 0.205	0.310
18	$ 0.084	$ 0.020	$ -	$ -	$ 0.020	0.110
19	$ (0.024)	$ 0.110	$ 0.025	$ -	$ 0.135	0.265
20	$ 0.027	$ 0.070	$ -	$ -	$ 0.070	0.135
21	$ 0.060	$ 0.100	$ 0.056	$ 0.090	$ 0.246	0.326
22	$ 0.107	$ 0.040	$ -	$ -	$ 0.040	0.165
23	$ 0.034	$ -	$ -	$ -	$ -	0.110
24	$ 0.111	$ 0.170	$ 0.110	$ -	$ 0.280	0.415
25	$ 0.031	$ 0.080	$ 0.015	$ -	$ 0.095	0.120
26	$ 0.073	$ 0.210	$ 0.042	$ -	$ 0.252	0.337
27	$ 0.034	$ 0.040	$ -	$ -	$ 0.040	0.080
28	$ 0.076	$ -	$ 0.110	$ 0.090	$ 0.200	0.300
29	$ 0.032	$ 0.060	$ -	$ -	$ 0.060	0.120
30	$ 0.069	$ 0.060	$ -	$ -	$ 0.060	0.115
31	$ 0.037	$ 0.080	$ 0.045	$ -	$ 0.125	0.170
32	$ (0.066)	$ 0.190	$ 0.025	$ 0.090	$ 0.305	0.345
33	$ 0.056	$ 0.070	$ 0.035	$ -	$ 0.105	0.185
34	$ (0.072)	$ 0.230	$ 0.047	$ -	$ 0.277	0.297
35	$ 0.077	$ 0.150	$ -	$ -	$ 0.150	0.245
36	$ 0.033	$ 0.180	$ 0.040	$ -	$ 0.220	0.275
37	$ 0.069	$ 0.020	$ -	$ -	$ 0.020	0.055
38	$ 0.115	$ -	$ -	$ -	$ -	0.135
39	$ 0.036	$ 0.190	$ 0.046	$ -	$ 0.236	0.336
40	$ 0.086	$ 0.020	$ -	$ 0.050	$ 0.070	0.200
Avg	**$ 0.0756**	**$ 0.0893**	**$ 0.0317**	**$ 0.0185**	**$ 0.139**	**0.215**

Table 4-5. Waterfall Variable Data and PPV

Proj. #	Project Cost Performance (PCP)	Project Time Performance (PTP)	Project Quality Performance (PQP)	Project HSE Performance (PHP)	Project Success Index (PSI)
1	$ 0.07	$ 0.230	$ 0.079	$ -	0.098
2	$ 0.12	$ -	$ 0.016	$ 0.070	0.053
3	$ 0.12	$ 0.050	$ 0.021	$ -	0.051
4	$ 0.11	$ 0.190	$ 0.010	$ -	0.081
5	$ 0.07	$ 0.260	$ 0.110	$ 0.070	0.128
6	$ 0.17	$ 0.040	$ -	$ -	0.057
7	$ 0.09	$ 0.060	$ 0.031	$ 0.050	0.058
8	$ 0.07	$ 0.120	$ -	$ 0.050	0.062
9	$ 0.05	$ 0.040	$ 0.095	$ -	0.048
10	$ 0.10	$ -	$ -	$ -	0.029
11	$ 0.11	$ 0.080	$ 0.069	$ -	0.069
12	$ 0.15	$ 0.080	$ 0.041	$ -	0.072
13	$ 0.14	$ 0.040	$ 0.077	$ -	0.069
14	$ 0.09	$ 0.130	$ -	$ 0.090	0.080
15	$ 0.14	$ -	$ 0.037	$ 0.090	0.068
16	$ 0.08	$ 0.040	$ -	$ -	0.032
17	$ 0.11	$ 0.120	$ 0.085	$ -	0.082
18	$ 0.09	$ 0.020	$ -	$ -	0.031
19	$ 0.13	$ 0.110	$ 0.025	$ -	0.072
20	$ 0.07	$ 0.070	$ -	$ -	0.037
21	$ 0.08	$ 0.100	$ 0.056	$ 0.090	0.081
22	$ 0.13	$ 0.040	$ -	$ -	0.046
23	$ 0.11	$ -	$ -	$ -	0.031
24	$ 0.14	$ 0.170	$ 0.110	$ -	0.109
25	$ 0.03	$ 0.080	$ 0.015	$ -	0.031
26	$ 0.09	$ 0.210	$ 0.042	$ -	0.088
27	$ 0.04	$ 0.040	$ -	$ -	0.022
28	$ 0.10	$ -	$ 0.110	$ 0.090	0.074
29	$ 0.06	$ 0.060	$ -	$ -	0.033
30	$ 0.05	$ 0.060	$ -	$ -	0.031
31	$ 0.04	$ 0.080	$ 0.045	$ -	0.044
32	$ 0.04	$ 0.190	$ 0.025	$ 0.090	0.086
33	$ 0.08	$ 0.070	$ 0.035	$ -	0.049
34	$ 0.02	$ 0.230	$ 0.047	$ -	0.076
35	$ 0.09	$ 0.150	$ -	$ -	0.066
36	$ 0.05	$ 0.180	$ 0.040	$ -	0.072
37	$ 0.04	$ 0.020	$ -	$ -	0.015
38	$ 0.14	$ -	$ -	$ -	0.039
39	$ 0.10	$ 0.190	$ 0.046	$ -	0.089
40	$ 0.13	$ 0.020	$ -	$ 0.050	0.053
Avg	**$ 0.09**	**$ 0.089**	**$ 0.032**	**$ 0.019**	**0.061**

Table 4-6. Waterfall Variable Data and PSI

Proj #	Bid(M)	BCost (M)	BCost (%)	BP (M)	BWD
1	$ 19.60	$ 17.91	91.40%	$ 1.69	220
2	$ 23.20	$ 21.40	92.25%	$ 1.80	155
3	$ 24.35	$ 22.38	91.90%	$ 1.97	145
4	$ 18.75	$ 17.20	91.75%	$ 1.55	140
5	$ 22.95	$ 21.23	92.50%	$ 1.72	120
6	$ 17.60	$ 16.02	91.00%	$ 1.58	140
7	$ 21.40	$ 19.56	91.40%	$ 1.84	155
8	$ 16.65	$ 15.28	91.75%	$ 1.37	115
9	$ 19.95	$ 18.05	90.50%	$ 1.90	170
10	$ 21.95	$ 20.08	91.50%	$ 1.87	200
11	$ 18.75	$ 17.11	91.25%	$ 1.64	210
12	$ 23.85	$ 21.89	91.80%	$ 1.96	205
13	$ 20.25	$ 18.48	91.25%	$ 1.77	190
14	$ 21.25	$ 19.36	91.10%	$ 1.89	180
15	$ 24.10	$ 21.99	91.25%	$ 2.11	195
16	$ 19.75	$ 18.09	91.60%	$ 1.66	185
17	$ 16.85	$ 15.39	91.35%	$ 1.46	170
18	$ 19.50	$ 17.76	91.10%	$ 1.74	185
19	$ 23.15	$ 21.23	91.70%	$ 1.92	175
20	$ 21.10	$ 19.10	90.50%	$ 2.00	195
21	$ 18.95	$ 17.23	90.90%	$ 1.72	180
22	$ 18.50	$ 16.96	91.65%	$ 1.54	185
23	$ 20.60	$ 19.01	92.30%	$ 1.59	195
24	$ 20.90	$ 19.09	91.35%	$ 1.81	175
25	$ 17.45	$ 15.75	90.25%	$ 1.70	185
26	$ 22.40	$ 20.59	91.90%	$ 1.81	185
27	$ 19.70	$ 18.03	91.50%	$ 1.67	195
28	$ 23.75	$ 21.80	91.80%	$ 1.95	180
29	$ 24.25	$ 22.12	91.20%	$ 2.13	190
30	$ 18.30	$ 16.73	91.40%	$ 1.57	185
31	$ 20.15	$ 18.58	92.20%	$ 1.57	195
32	$ 21.70	$ 19.83	91.40%	$ 1.87	200
33	$ 19.75	$ 17.87	90.50%	$ 1.88	180
34	$ 16.20	$ 14.79	91.30%	$ 1.41	185
35	$ 18.15	$ 16.65	91.75%	$ 1.50	195
36	$ 16.85	$ 15.47	91.80%	$ 1.38	200
37	$ 17.95	$ 16.67	92.85%	$ 1.28	180
38	$ 18.40	$ 16.79	91.25%	$ 1.61	190
39	$ 17.50	$ 16.04	91.65%	$ 1.46	170
40	$ 16.65	$ 15.07	90.50%	$ 1.58	185
Avg	**$ 20.08**	**$ 18.36**	**91.46%**	**$ 1.71**	**179.63**

Table 4-7. Agile Project Bid Data

Proj #	Final (M)	FCost (M)	FCost (%)	FP (M)	FWD	C_{Delta} (M)	P_{Delta} (M)
1	$ 20.50	$ 18.61	90.80%	$ 1.89	219	$ 0.70	$ 0.20
2	$ 23.90	$ 21.99	92.00%	$ 1.91	149	$ 0.59	$ 0.11
3	$ 24.85	$ 22.74	91.50%	$ 2.11	141	$ 0.36	$ 0.14
4	$ 19.15	$ 17.46	91.15%	$ 1.69	142	$ 0.25	$ 0.15
5	$ 24.25	$ 22.49	92.75%	$ 1.76	126	$ 1.26	$ 0.04
6	$ 18.40	$ 16.88	91.75%	$ 1.52	144	$ 0.87	$ (0.07)
7	$ 22.10	$ 20.53	92.90%	$ 1.57	156	$ 0.97	$ (0.27)
8	$ 18.25	$ 16.70	91.50%	$ 1.55	121	$ 1.42	$ 0.18
9	$ 20.85	$ 18.77	90.00%	$ 2.09	176	$ 0.71	$ 0.19
10	$ 22.95	$ 20.91	91.10%	$ 2.04	194	$ 0.82	$ 0.18
11	$ 19.60	$ 17.86	91.10%	$ 1.74	204	$ 0.75	$ 0.10
12	$ 25.25	$ 23.10	91.50%	$ 2.15	215	$ 1.21	$ 0.19
13	$ 21.50	$ 19.87	92.40%	$ 1.63	196	$ 1.39	$ (0.14)
14	$ 21.75	$ 19.79	91.00%	$ 1.96	169	$ 0.43	$ 0.07
15	$ 24.90	$ 22.66	91.00%	$ 2.24	184	$ 0.67	$ 0.13
16	$ 21.20	$ 19.50	92.00%	$ 1.70	190	$ 1.41	$ 0.04
17	$ 18.05	$ 16.47	91.25%	$ 1.58	156	$ 1.08	$ 0.12
18	$ 20.85	$ 19.00	91.15%	$ 1.85	164	$ 1.24	$ 0.11
19	$ 23.85	$ 21.82	91.50%	$ 2.03	156	$ 0.59	$ 0.11
20	$ 21.70	$ 19.61	90.35%	$ 2.09	210	$ 0.51	$ 0.09
21	$ 20.05	$ 18.20	90.75%	$ 1.85	172	$ 0.97	$ 0.13
22	$ 19.45	$ 17.80	91.50%	$ 1.65	186	$ 0.84	$ 0.11
23	$ 21.00	$ 19.38	92.30%	$ 1.62	189	$ 0.37	$ 0.03
24	$ 21.05	$ 19.21	91.25%	$ 1.84	184	$ 0.12	$ 0.03
25	$ 17.65	$ 15.93	90.25%	$ 1.72	169	$ 0.18	$ 0.02
26	$ 24.05	$ 22.08	91.80%	$ 1.97	182	$ 1.49	$ 0.16
27	$ 21.30	$ 19.49	91.50%	$ 1.81	204	$ 1.46	$ 0.14
28	$ 24.25	$ 22.25	91.75%	$ 2.00	172	$ 0.45	$ 0.05
29	$ 24.95	$ 22.78	91.30%	$ 2.17	178	$ 0.66	$ 0.04
30	$ 19.10	$ 17.40	91.10%	$ 1.70	193	$ 0.67	$ 0.13
31	$ 20.70	$ 19.10	92.25%	$ 1.60	197	$ 0.52	$ 0.03
32	$ 22.60	$ 20.68	91.50%	$ 1.92	206	$ 0.85	$ 0.05
33	$ 20.90	$ 18.94	90.60%	$ 1.96	178	$ 1.06	$ 0.09
34	$ 17.20	$ 15.70	91.25%	$ 1.51	164	$ 0.90	$ 0.10
35	$ 19.20	$ 17.60	91.65%	$ 1.60	207	$ 0.94	$ 0.11
36	$ 18.25	$ 16.74	91.75%	$ 1.51	212	$ 1.28	$ 0.12
37	$ 18.40	$ 17.14	93.15%	$ 1.26	175	$ 0.47	$ (0.02)
38	$ 19.10	$ 17.38	91.00%	$ 1.72	174	$ 0.59	$ 0.11
39	$ 17.75	$ 16.24	91.50%	$ 1.51	173	$ 0.20	$ 0.05
40	$ 17.55	$ 15.88	90.50%	$ 1.67	169	$ 0.81	$ 0.09
Avg	**$ 20.96**	**$ 19.17**	**91.43%**	**$ 1.79**	**177.40**	**$ 0.802**	**$ 0.081**

Table 4-8. Agile Project Outcome Data

Proj #	Quality Incidents			Safety Incidents		
	Count	Cost ($)	Days	Total	Lost Time	Time Lost
1	1	$ 29,500.00	14	7	0	0
2	3	$ 13,500.00	9	5	1	6.67
3	4	$ 11,650.00	7	3	0	0
4	1	$ 43,000.00	17	9	1	5.8
5	0	$ -	0	2	0	0
6	3	$ 8,450.00	2	3	0	0
7	0	$ -	0	2	0	0
8	0	$ -	0	4	0	0
9	4	$ 10,950.00	8	5	0	0
10	2	$ 42,000.00	11	4	0	0
11	2	$ 5,600.00	3	5	1	4.2
12	0	$ -	0	3	0	0
13	3	$ 9,400.00	2	0	0	0
14	2	$ 5,250.00	1	3	0	0
15	2	$ 18,300.00	8	4	0	0
16	0	$ -	0	3	1	0.9
17	0	$ -	0	0	0	0
18	2	$ 7,600.00	5	3	0	0
19	2	$ 6,350.00	2	4	1	5
20	0	$ -	0	6	0	0
21	1	$ 9,250.00	2	2	0	0
22	2	$ 22,650.00	1	6	1	4.2
23	3	$ 11,700.00	4	0	0	0
24	1	$ 9,400.00	3	2	0	0
25	0	$ -	0	5	0	0
26	2	$ 18,300.00	4	3	0	0
27	4	$ 43,000.00	8	4	0	0
28	0	$ -	0	1	0	0
29	1	$ 42,450.00	6	5	1	6.7
30	3	$ 41,100.00	7	4	0	0
31	2	$ 13,800.00	2	4	0	0
32	2	$ 41,900.00	1	3	0	0
33	0	$ -	0	6	1	5.4
34	1	$ 12,500.00	3	2	0	0
35	0	$ -	0	3	2	3.33
36	2	$ 8,700.00	2	4	0	0
37	0	$ -	0	4	1	6.25
38	0	$ -	0	3	1	3.75
39	0	$ -	0	6	0	0
40	3	$ 15,400.00	3	4	0	0
Avg	**1.45**	**$ 12,542.50**	**3.38**	**3.65**	**0.300**	**1.31**

Table 4-9. Agile Quality and Safety Data

Proj #	$C_{DProject}$ (M)	C_{Sched} (M)	C_{Qual} (M)	C_{safe} (M)	C_{TSCQSF} (M)	Project Performance Value (PPV)
1	$ 0.050	$ -	$ 0.030	$ -	$ 0.030	0.080
2	$ 0.048	$ -	$ 0.014	$ 0.080	$ 0.094	0.142
3	$ 0.022	$ -	$ 0.012	$ -	$ 0.012	0.034
4	$ 0.010	$ 0.020	$ 0.043	$ 0.070	$ 0.133	0.143
5	$ 0.122	$ 0.060	$ -	$ -	$ 0.060	0.182
6	$ 0.094	$ 0.040	$ 0.008	$ -	$ 0.048	0.142
7	$ 0.124	$ 0.010	$ -	$ -	$ 0.010	0.134
8	$ 0.124	$ 0.060	$ -	$ -	$ 0.060	0.184
9	$ 0.052	$ 0.060	$ 0.011	$ -	$ 0.071	0.123
10	$ 0.064	$ -	$ 0.042	$ -	$ 0.042	0.106
11	$ 0.065	$ -	$ 0.006	$ 0.050	$ 0.056	0.121
12	$ 0.102	$ 0.100	$ -	$ -	$ 0.100	0.202
13	$ 0.153	$ 0.060	$ 0.009	$ -	$ 0.069	0.222
14	$ 0.036	$ -	$ 0.005	$ -	$ 0.005	0.041
15	$ 0.054	$ -	$ 0.018	$ -	$ 0.018	0.072
16	$ 0.137	$ 0.050	$ -	$ 0.011	$ 0.061	0.198
17	$ 0.096	$ -	$ -	$ -	$ -	0.096
18	$ 0.113	$ -	$ 0.008	$ -	$ 0.008	0.121
19	$ 0.048	$ -	$ 0.006	$ 0.060	$ 0.066	0.114
20	$ 0.042	$ 0.150	$ -	$ -	$ 0.150	0.192
21	$ 0.084	$ -	$ 0.009	$ -	$ 0.009	0.093
22	$ 0.073	$ 0.010	$ 0.023	$ 0.050	$ 0.083	0.156
23	$ 0.034	$ -	$ 0.012	$ -	$ 0.012	0.046
24	$ 0.009	$ 0.090	$ 0.009	$ -	$ 0.099	0.108
25	$ 0.016	$ -	$ -	$ -	$ -	0.016
26	$ 0.133	$ -	$ 0.018	$ -	$ 0.018	0.151
27	$ 0.132	$ 0.090	$ 0.043	$ -	$ 0.133	0.265
28	$ 0.040	$ -	$ -	$ -	$ -	0.040
29	$ 0.062	$ -	$ 0.042	$ 0.080	$ 0.123	0.184
30	$ 0.054	$ 0.080	$ 0.041	$ -	$ 0.121	0.175
31	$ 0.049	$ 0.020	$ 0.014	$ -	$ 0.034	0.083
32	$ 0.080	$ 0.060	$ 0.042	$ -	$ 0.102	0.182
33	$ 0.097	$ -	$ -	$ 0.065	$ 0.065	0.162
34	$ 0.080	$ -	$ 0.013	$ -	$ 0.013	0.093
35	$ 0.083	$ 0.120	$ -	$ 0.040	$ 0.160	0.243
36	$ 0.116	$ 0.120	$ 0.009	$ -	$ 0.129	0.245
37	$ 0.049	$ -	$ -	$ 0.075	$ 0.075	0.124
38	$ 0.048	$ -	$ -	$ 0.045	$ 0.045	0.093
39	$ 0.015	$ 0.030	$ -	$ -	$ 0.030	0.045
40	$ 0.072	$ -	$ 0.015	$ -	$ 0.015	0.087
Avg	**$ 0.0721**	**$ 0.0308**	**$ 0.0126**	**$ 0.0157**	**$ 0.059**	**0.131**

Table 4-10. Agile Variable Data and PPV

Proj. #	Project Cost Performance (PCP)	Project Time Performance (PTP)	Project Quality Performance (PQP)	Project HSE Performance (PHP)	Project Success Index (PSI)
1	$ 0.09	$ -	$ 0.030	$ -	0.033
2	$ 0.07	$ -	$ 0.014	$ 0.080	0.040
3	$ 0.05	$ -	$ 0.012	$ -	0.017
4	$ 0.04	$ 0.020	$ 0.043	$ 0.070	0.042
5	$ 0.13	$ 0.060	$ -	$ -	0.053
6	$ 0.08	$ 0.040	$ 0.008	$ -	0.035
7	$ 0.07	$ 0.010	$ -	$ -	0.023
8	$ 0.16	$ 0.060	$ -	$ -	0.061
9	$ 0.09	$ 0.060	$ 0.011	$ -	0.044
10	$ 0.10	$ -	$ 0.042	$ -	0.039
11	$ 0.09	$ -	$ 0.006	$ 0.050	0.036
12	$ 0.14	$ 0.100	$ -	$ -	0.066
13	$ 0.13	$ 0.060	$ 0.009	$ -	0.053
14	$ 0.05	$ -	$ 0.005	$ -	0.016
15	$ 0.08	$ -	$ 0.018	$ -	0.027
16	$ 0.15	$ 0.050	$ -	$ 0.011	0.057
17	$ 0.12	$ -	$ -	$ -	0.034
18	$ 0.14	$ -	$ 0.008	$ -	0.040
19	$ 0.07	$ -	$ 0.006	$ 0.060	0.034
20	$ 0.06	$ 0.150	$ -	$ -	0.056
21	$ 0.11	$ -	$ 0.009	$ -	0.034
22	$ 0.09	$ 0.010	$ 0.023	$ 0.050	0.046
23	$ 0.04	$ -	$ 0.012	$ -	0.014
24	$ 0.02	$ 0.090	$ 0.009	$ -	0.030
25	$ 0.02	$ -	$ -	$ -	0.006
26	$ 0.17	$ -	$ 0.018	$ -	0.052
27	$ 0.16	$ 0.090	$ 0.043	$ -	0.079
28	$ 0.05	$ -	$ -	$ -	0.014
29	$ 0.07	$ -	$ 0.042	$ 0.080	0.048
30	$ 0.08	$ 0.080	$ 0.041	$ -	0.053
31	$ 0.06	$ 0.020	$ 0.014	$ -	0.024
32	$ 0.09	$ 0.060	$ 0.042	$ -	0.051
33	$ 0.12	$ -	$ -	$ 0.065	0.047
34	$ 0.10	$ -	$ 0.013	$ -	0.032
35	$ 0.11	$ 0.120	$ -	$ 0.040	0.069
36	$ 0.14	$ 0.120	$ 0.009	$ -	0.073
37	$ 0.04	$ -	$ -	$ 0.075	0.029
38	$ 0.07	$ -	$ -	$ 0.045	0.030
39	$ 0.03	$ 0.030	$ -	$ -	0.015
40	$ 0.09	$ -	$ 0.015	$ -	0.029
Avg	**$ 0.089**	**$ 0.031**	**$ 0.013**	**$ 0.016**	**0.0398**

Table 4-11. Agile Variable Data and PSI

The second approach considered that even though the numerical values show an improvement in performance, this could be misleading. Numerical values alone may not necessarily prove there is any certainty in improvement going from waterfall to agile, so the need to perform a statistical analysis of the data was recognized. This statistical analysis can be found in summary form in Tables 4-12. *"Distribution Summary"* and 4-13. *"Test Summary"* in Chapter 4.9 *"Summary"*. The actual statistical analysis data can be found in chapters 4.2 *"Waterfall Cost and Agile Cost Data Analysis"* through 4.8 "*Waterfall PSI and Waterfall PPV Data Analysis"*

4.2 Waterfall Cost and Agile Cost Data Analysis

The first step in evaluating all of the cost data from a statistical analysis perspective has to do with whether or not it is normally distributed. When the data is normally distributed, it can be analyzed using the t-Test for statistical significance. When it is not normally distributed, a non-parametric approach must be used. Considering Figure 4-1. *"Waterfall Cost Probability Plot"*, the P-Value is greater than 0.05, proving that the costs associated with variation on the waterfall projects are normally distributed. The cost value referenced was calculated in Chapter 3 as $\mathbf{C_{TProject}}$ **($M)** for both data sets.

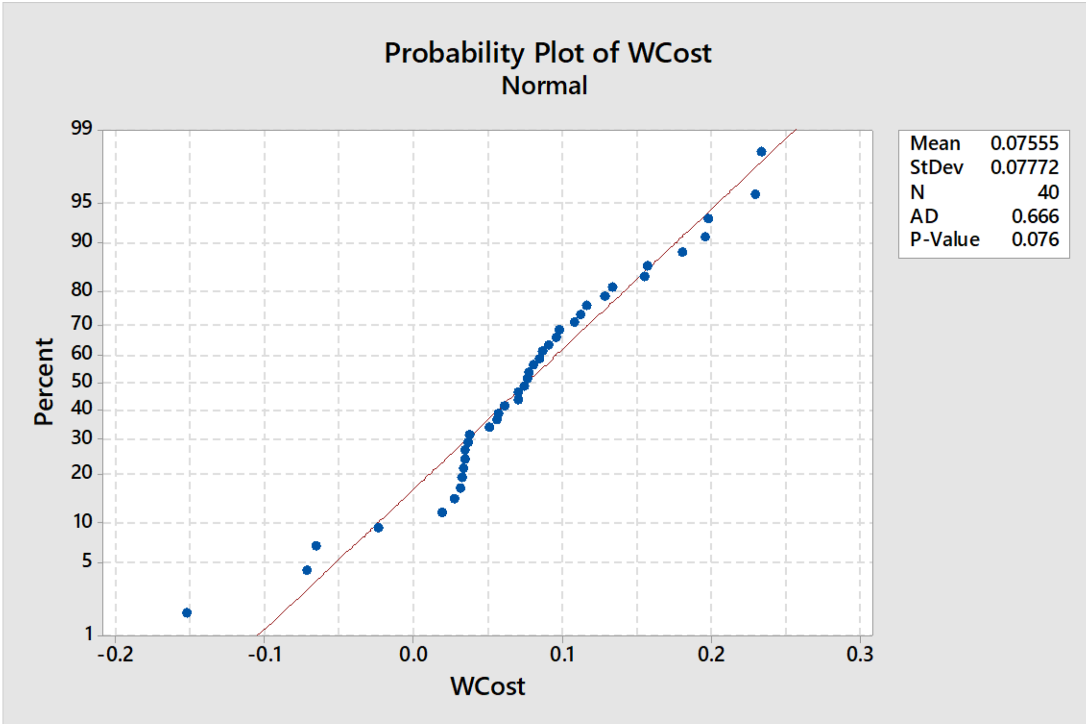

Figure 4-1. Waterfall Cost Probability Plot

Upon review of Figure 4-2. *"Agile Cost Probability Plot"*, the P-Value is also greater than 0.05, proving that the costs associated with variation on the agile projects are normally distributed.

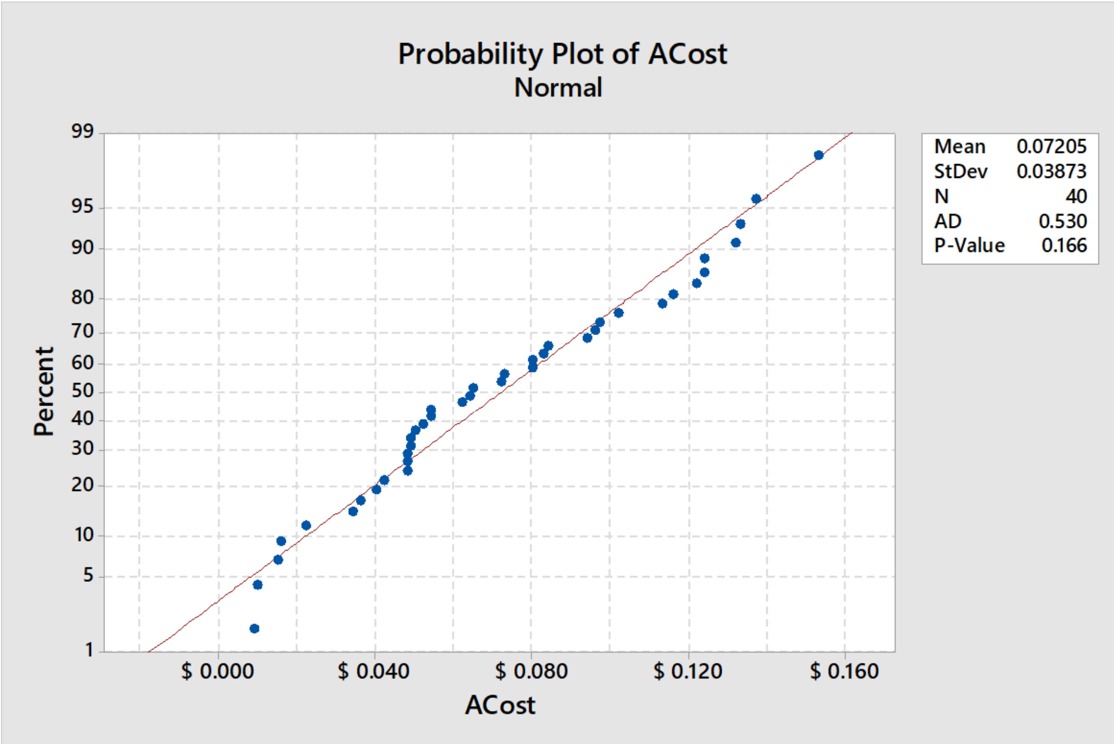

Figure 4-2. Agile Cost Probability Plot

As these two data sets are normally distributed, it shows that there is a good sampling of data overall, as one would expect variable costs to be linearly related to the overall project value. Since the data shown in both Figure 4-1.*"Waterfall Cost Probability Plot"* and Figure 4-2. *"Agile Cost Probability Plot"* is normally distributed, then the data can be compared using the 2-Sample t-Test to see if there is a significant difference between the mean of the two cost data sets. Tests were conducted using Minitab 2018 and as found in Figure 4-3. *"Cost 2-Sample, t-Test Results"*, the P-Value is greater than 0.05. This indicates that there is not a statistically significant difference between the means and therefore, the null hypothesis that states "Applying agile methodologies to heavy-civil bridge construction projects will not reduce costs associated with variations or changes" cannot be rejected.

Two-Sample T-Test and CI: WCost, ACost				
Method				
μ_1: Mean of WCost		Equal variances are not assumed for this analysis.		
μ_2: Mean of ACost				
Difference: $\mu_1 - \mu_2$				
Descriptive Statistics				
Sample	N	Mean	StDev	SE Mean
WCost	40	0.0755	0.0777	0.012
ACost	40	0.0721	0.0387	0.0061
Estimation for Difference				
Difference		95% CI for Difference		
0.0035		(-0.0240, 0.0310)		
Test				
Null Hypothesis			H_0: $\mu_1 - \mu_2 = 0$	
Alternative Hypothesis			H_1: $\mu_1 - \mu_2 \neq 0$	
T-Value		DF	P-Value	
0.25		57	0.800	

Figure 4-3. Cost 2-Sample t-Test Results

4.3 Waterfall Schedule and Agile Schedule Data Analysis

With all of the datasets, evaluation continued for normality first. Looking at Figure 4-4. *"Waterfall Schedule Probability Plot"*, the P-Value is less than 0.05, proving that the costs associated with the schedule on waterfall projects are not normally distributed. This is likely due to the zero-value instances where there were no added costs due to schedule increases or changes. This cost value due to schedule was calculated in Chapter 3 as $\mathbf{C_{Sched}}$ **($M).**

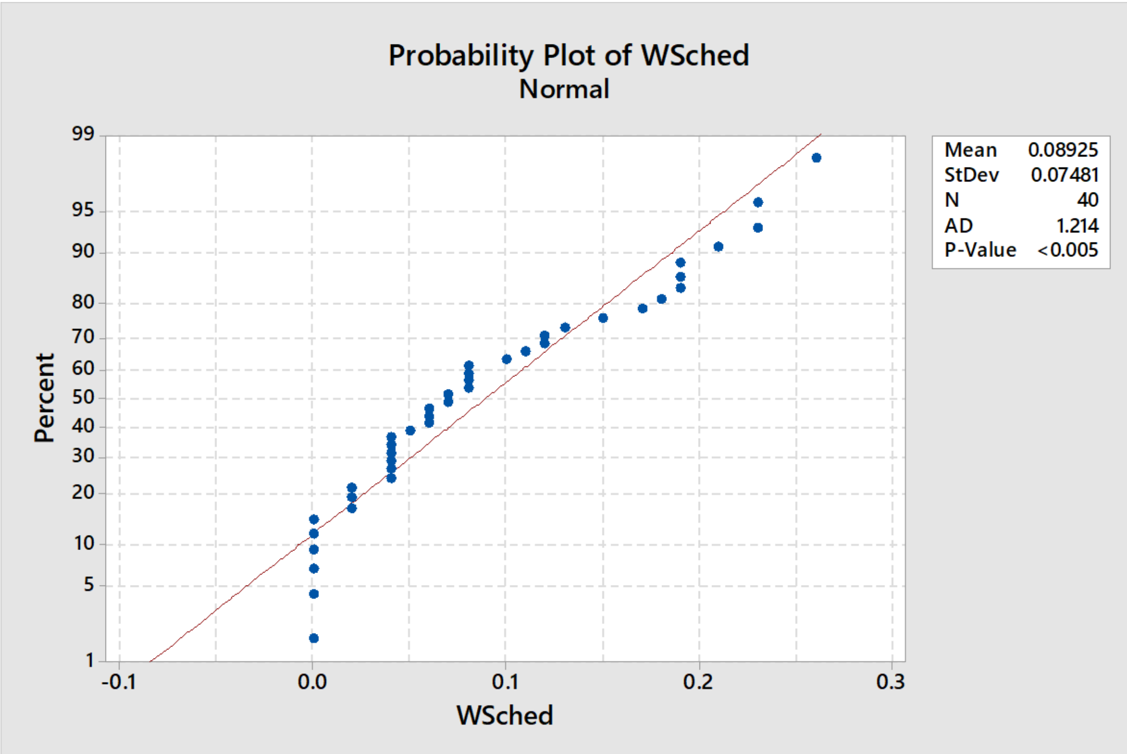

Figure 4-4. Waterfall Schedule Probability Plot

Considering the Figure 4-5. *"Agile Schedule Probability Plot"*, the P-Value is also less than 0.05, proving that the costs associated with schedule on the agile projects are not normally distributed. For the agile dataset, there are a significant amount of zero-values for the various projects, therefore leading to a non-parametric distribution. Zero values occur because some projects don't have scheduling costs beyond what was projected or actually finish early. This is not uncommon.

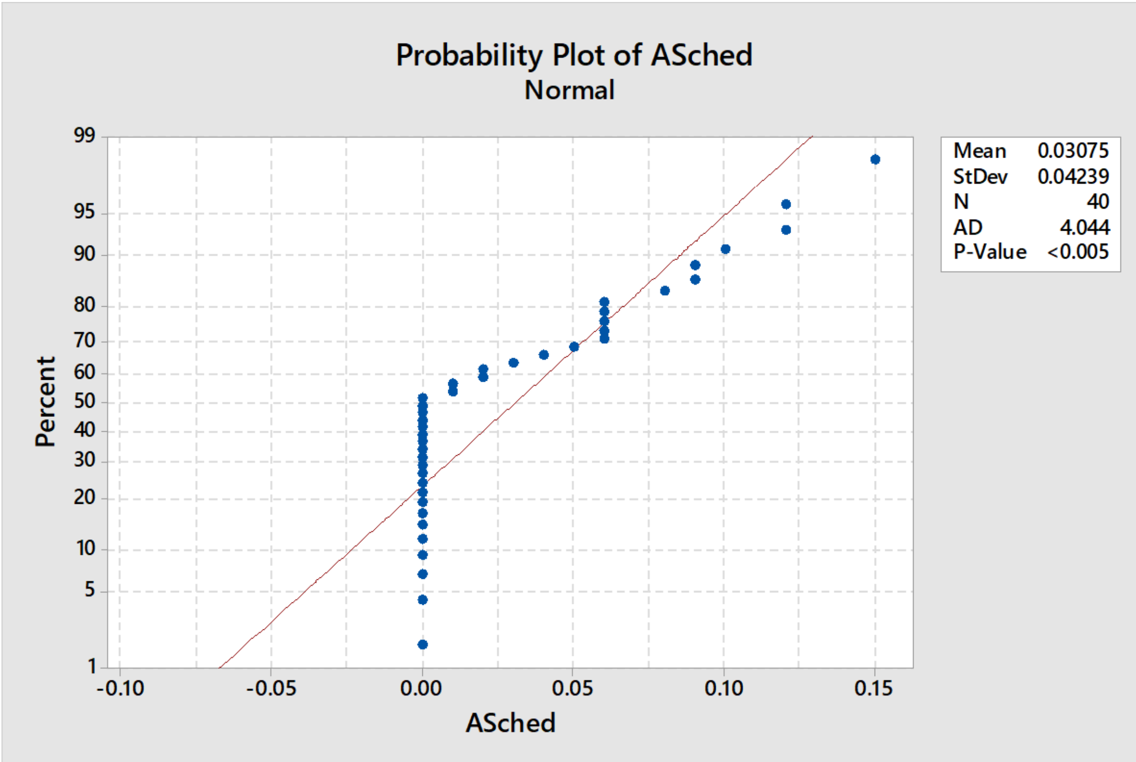

Figure 4-5. Agile Schedule Probability Plot

Since the data shown in both Figure 4-4. *"Waterfall Schedule Probability Plot"* and Figure 4-5. *"Agile Schedule Probability Plot"* is not normally distributed, then we cannot use the 2-Sample t-Test, as used with the cost data. Instead, the schedule data must be compared using a non-parametric test to see if there is a significant difference between the median of the two schedule data sets. In this case, the Mann-Whitney non-parametric test was applied. Tests were conducted using Minitab 2018 and as found in Figure 4-6. *"Schedule Mann-Whitney Non-Parametric Test"*, the P-Value is less than 0.05. This indicates that there is a statistically significant difference between the medians and the null hypothesis that states "Applying agile methodologies to heavy-civil bridge construction projects will not reduce costs associated with schedule delays" is rejected.

Mann-Whitney: WSched, ASched			
Method			
η_1: Mean of WSched η_2: Mean of ASched Difference: $\eta_1 - \eta_2$			
Descriptive Statistics			
Sample	N	Median	
WSched	40	0.07	
ASched	40	0.00	
Estimation for Difference			
Difference	95% CI for Difference	Achieved Confidence	
0.04	(-0.02, 0.07)	95.09%	
Test			
Null Hypothesis		$H_0: \eta_1 - \eta_2 = 0$	
Alternative Hypothesis		$H_1: \eta_1 - \eta_2 \neq 0$	
Method		W-Value	P-Value
Not Adjusted for Ties		2021.00	0.000
Adjusted for Ties		2021.00	0.000

Figure 4-6. Schedule Mann-Whitney Non-Parametric Test.

4.4 Waterfall Quality and Agile Quality Data Analysis

As discussed, establishing the type of distribution in order to determine the test approach is required. Considering the Figure 4-7. *"Waterfall Quality Probability Plot"*, the P-Value is less than 0.05, proving that the costs associated with the quality on waterfall projects are not normally distributed. This is also likely due to the zero-value instances where there were no added costs due to quality increases or changes. This cost value was calculated in Chapter 3 as **C_{Qual} ($M).**

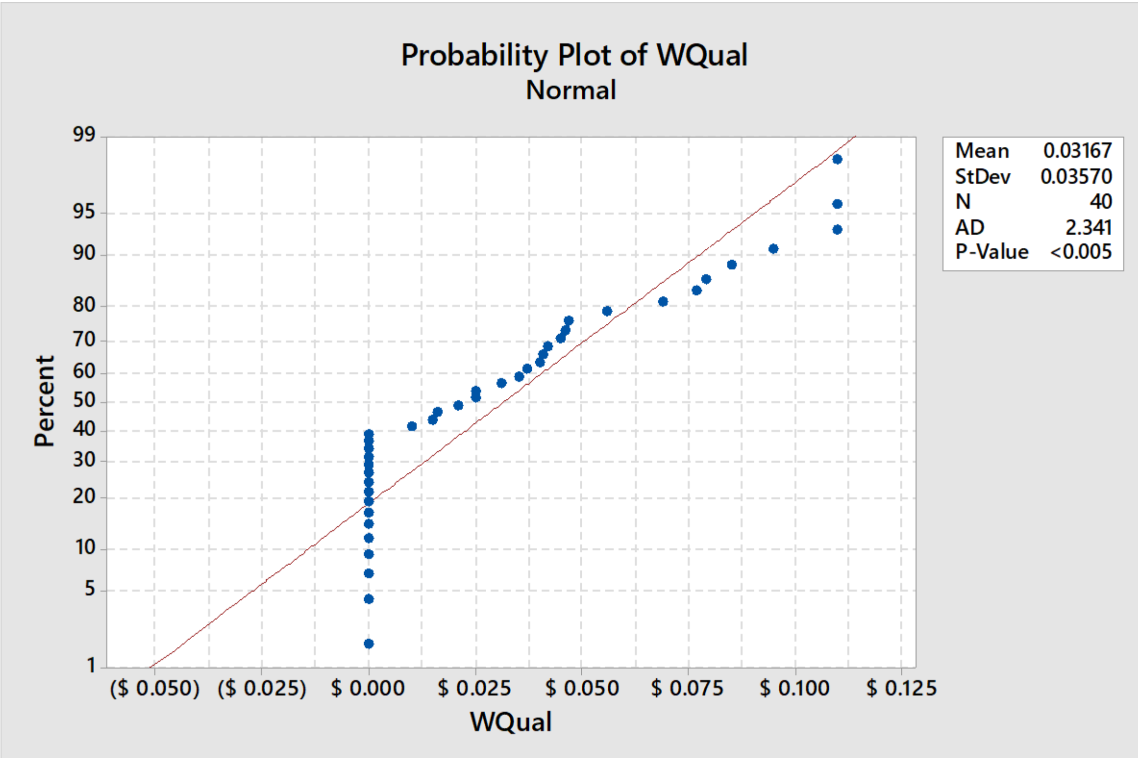

Figure 4-7. Waterfall Quality Probability Plot

Considering the Figure 4-8. *"Agile Quality Probability Plot"*, the P-Value is also less than 0.05, proving that the costs associated with quality on the agile projects are not normally distributed. For the agile dataset, there are a significant amount of zero-values for the various projects, therefore leading to a non-parametric distribution. Zero values occur because some projects don't have quality cost issues. This is not uncommon.

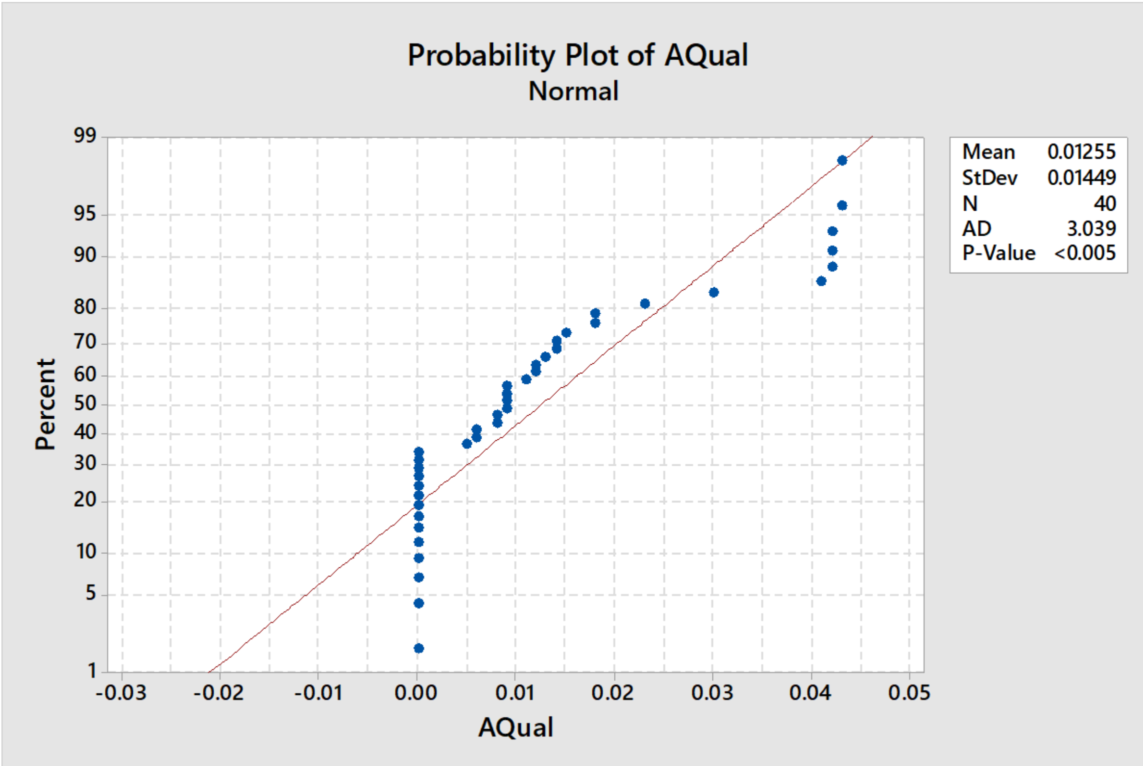

Figure 4-8. Agile Quality Probability Plot

Since the data shown in both Figure 4-7. *"Waterfall Quality Probability Plot"* and Figure 4-8. *"Agile Quality Probability Plot"* is not normally distributed, then we cannot use the 2-Sample t-Test, as used with the cost data. Instead, the quality data must be compared using a non-parametric test to see if there is a significant difference between the median of the two quality data Sets. In this case, the Mann-Whitney non-parametric test was applied. Tests were conducted using Minitab 2018 and as found in Figure 4-9. *"Quality Mann-Whitney Non-Parametric Test"*, the P-Value is less than 0.05. This indicates that there is a statistically significant difference between the medians and therefore, the null hypothesis that states "Applying agile methodologies to heavy-civil bridge construction projects will not reduce costs associated with quality rework" is rejected.

Mann-Whitney: WQual, AQual			
Method			
η_1: Mean of WQual η_2: Mean of AQual Difference: $\eta_1 - \eta_2$			
Descriptive Statistics			
Sample	N	Median	
WQual	40	0.033	
AQual	40	0.009	
Estimation for Difference			
Difference	95% CI for Difference	Achieved Confidence	
0.019	(0.00, 0.035)	95.09%	
Test			
Null Hypothesis		$H_0: \eta_1 - \eta_2 = 0$	
Alternative Hypothesis		$H_1: \eta_1 - \eta_2 \neq 0$	
Method		W-Value	P-Value
Not Adjusted for Ties		1882.50	0.012
Adjusted for Ties		1882.50	0.010

Figure 4-9. Quality Mann-Whitney Non-Parametric Test.

4.5 Waterfall Safety and Agile Safety Data Analysis

Evaluating the waterfall safety data set for normal distribution yielded similar results to the waterfall schedule and waterfall quality data sets. Considering Figure 4-10. *"Waterfall Safety Probability Plot"*, the P-Value is less than 0.05, proving that the costs associated with the safety on waterfall projects are not normally distributed. This is also likely due to the zero-value instances where there were no added costs due to safety increases or changes. This cost value was calculated in Chapter 3 as **C_{Safe} ($M).**

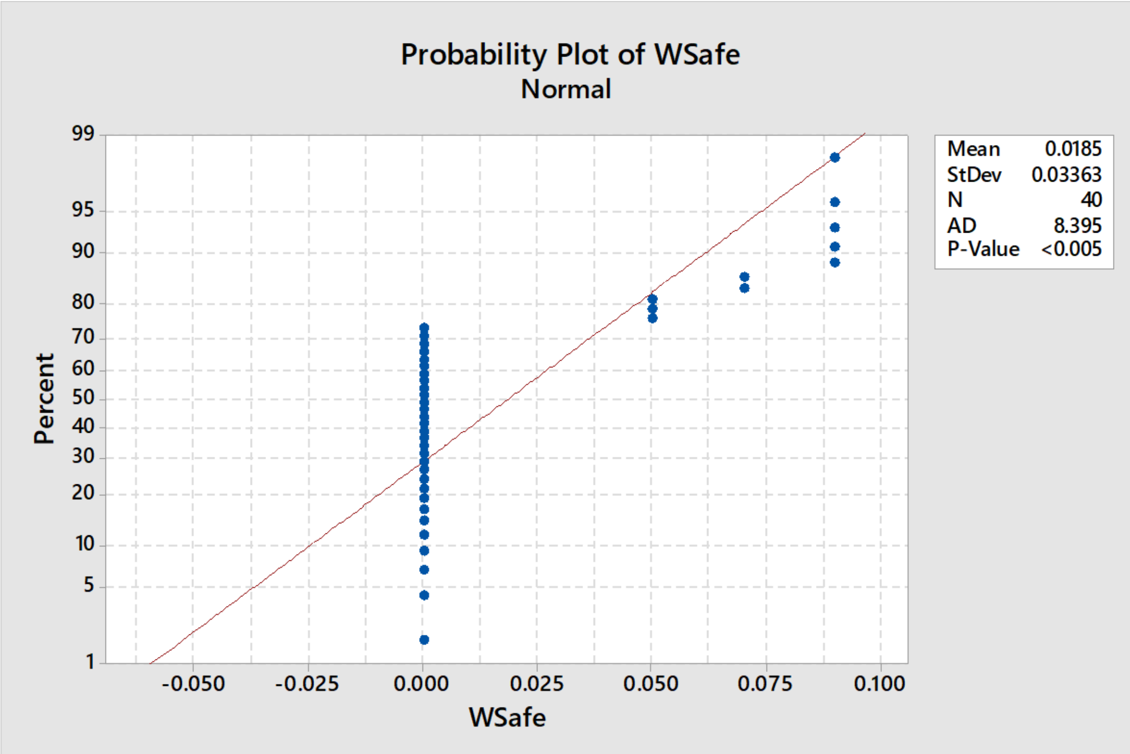

Figure 4-10. Waterfall Safety Probability Plot

Considering the Figure 4-11. *"Agile Safety Probability Plot"*, the P-Value is also less than 0.05, proving that the costs associated with safety on the agile projects are not normally distributed. For the agile dataset, there are a significant amount of zero-values for the various projects, therefore leading to a non-parametric distribution. Zero values occur because some projects don't have lost-time safety incidents.

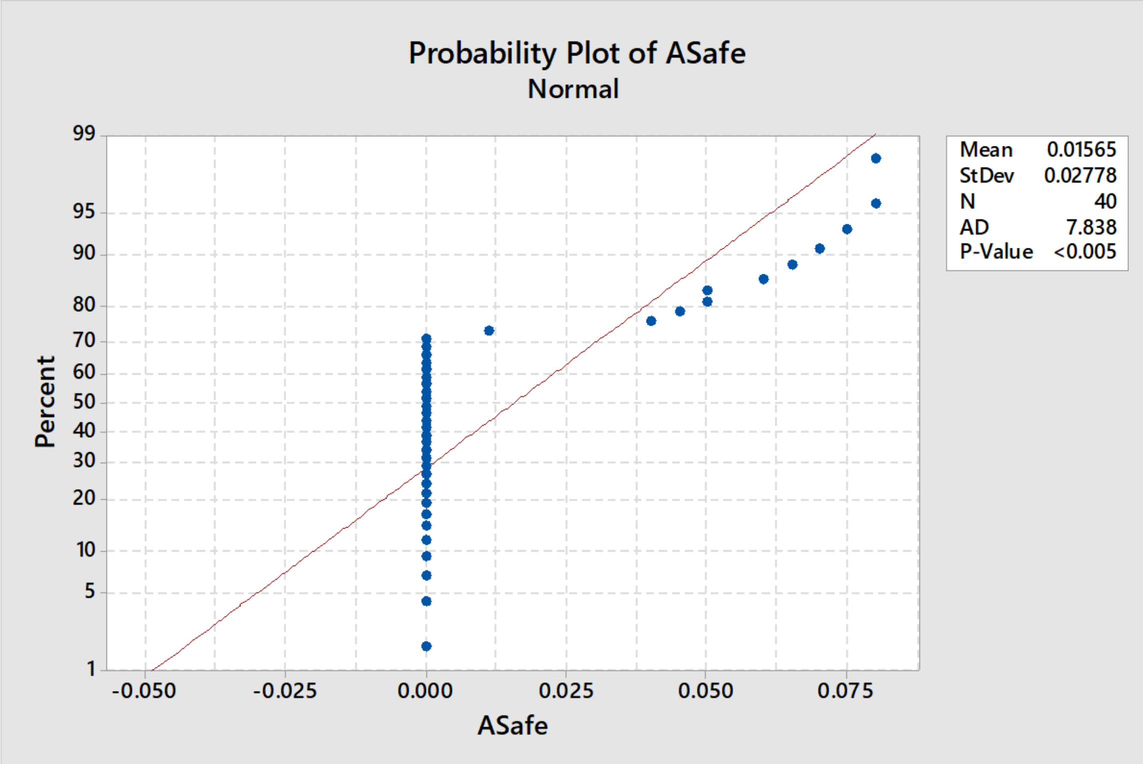

Figure 4-11. Agile Safety Probability Plot

Since the data shown in both Figure 4-10. *"Waterfall Safety Probability Plot"* and Figure 4-11. *"Agile Safety Probability Plot"* is not normally distributed, then we cannot use the 2-Sample t-Test, as used with the Cost Data. Instead, the schedule data must be compared using a non-parametric test to see if there is a significant difference between the medians of the two safety data sets. In this case, the Mann-Whitney non-parametric test was applied. Tests were conducted using Minitab 2018 and as found in Figure 4-12. *"Safety Mann-Whitney Non-Parametric Test"*, the P-Value is greater than 0.05. This indicates that there is not a statistically significant difference between the medians and therefore, the null hypothesis that states "Applying agile methodologies to heavy-civil bridge construction projects will not reduce costs associated with lost-time safety incidents" cannot be rejected.

Mann-Whitney: WSafe, ASafe			
Method			
η_1: Mean of WSafe **η_2: Mean of ASafe** **Difference: $\eta_1 - \eta_2$**			
Descriptive Statistics			
Sample	**N**	**Median**	
WQual	40	0.00	
AQual	40	0.00	
Estimation for Difference			
Difference	**95% CI for Difference**	**Achieved Confidence**	
0.00	(0.00, 0.00)	95.09%	
Test			
Null Hypothesis		**H_0: $\eta_1 - \eta_2 = 0$**	
Alternative Hypothesis		**H_1: $\eta_1 - \eta_2 \neq 0$**	
Method		**W-Value**	**P-Value**
Not Adjusted for Ties		1627.00	0.950
Adjusted for Ties		1627.00	0.936

Figure 4-12. Safety Mann-Whitney Non-Parametric Test.

4.6 Waterfall PSI and Agile PSI Data Analysis

After evaluating the data, calculations are performed to determine what the Project Success Index (PSI) values are, as detailed in Chapter 2.5. "*Scoring Methods*". Once these are calculated, we can evaluate the PSI scores for normal distribution. Considering Figure 4-13. *"Waterfall Project Success Index Probability Plot"*, the P-Value is greater than 0.05, proving the PSI distribution for waterfall projects is normal.

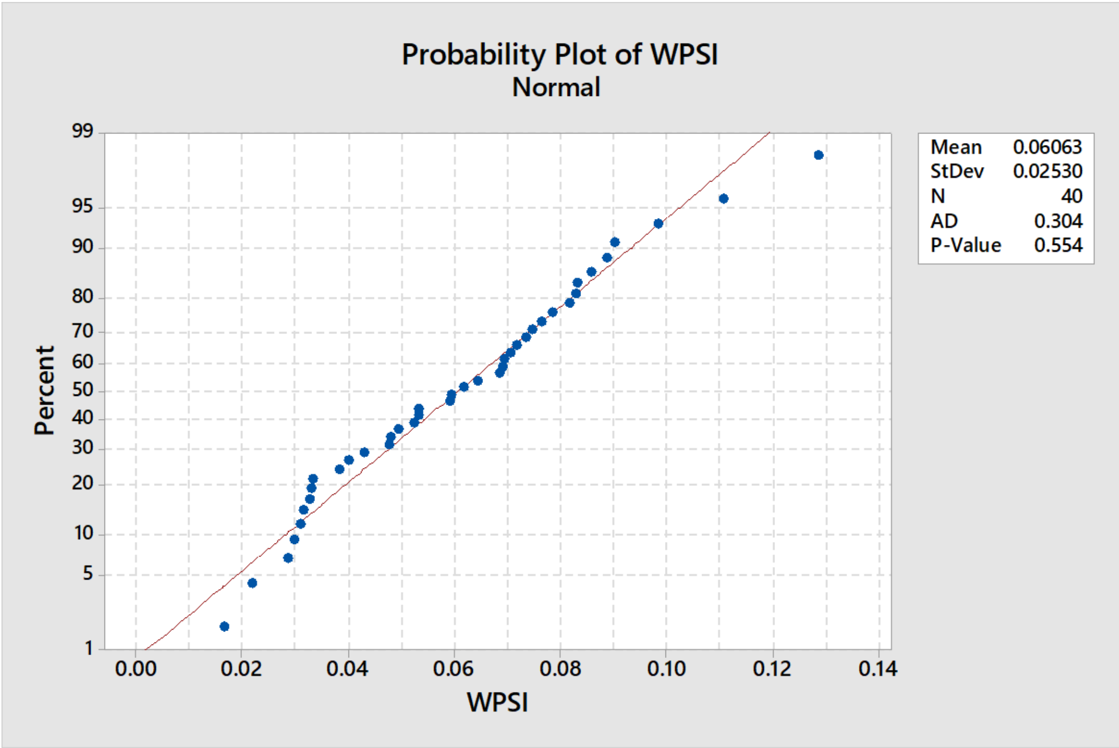

Figure 4-13. Waterfall Project Success Index Probability Plot

Considering Figure 4-14. *"Agile Project Success Index Probability Plot"*, the P-Value is greater than 0.05, proving the PSI distribution for agile projects is also normal.

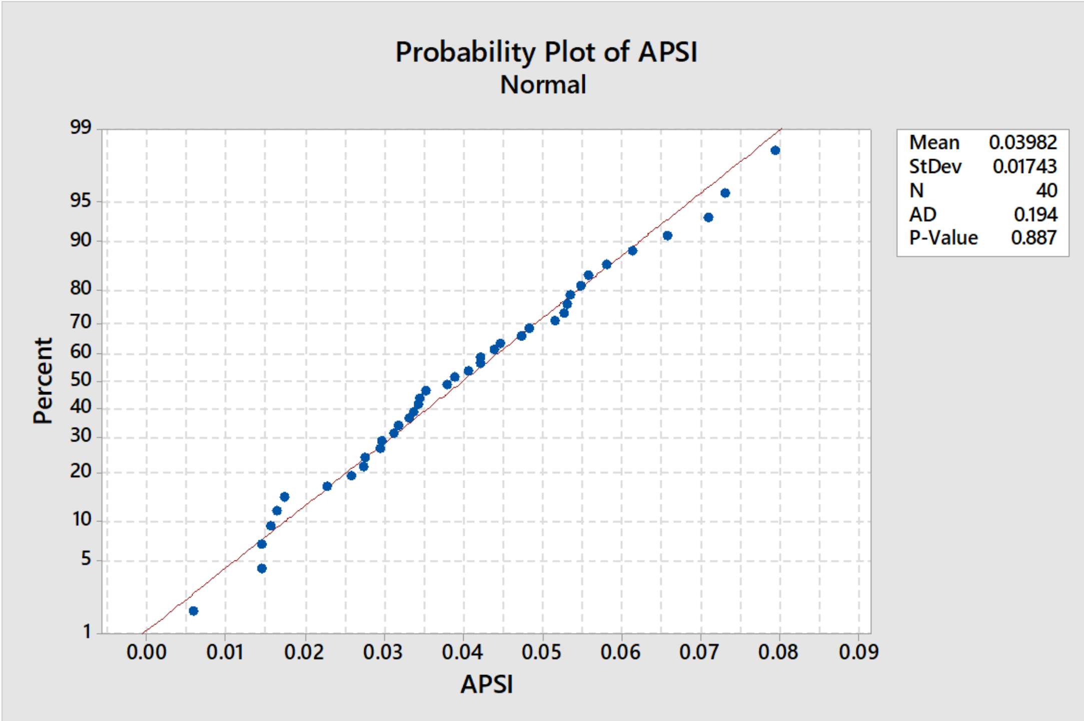

Figure 4-14. Agile Project Success Index Probability Plot

Since the data shown in both Figure 4-13. *"Waterfall Project Success Index Probability Plot"* and Figure 4-14. *"Agile Project Success Index Probability Plot"* is normally distributed, then the data can be compared using the 2-Sample t-Test to see if there is a significant difference between the means of the two PSI data sets. Tests were conducted using Minitab 2018 and as found in Figure 4-15. *"Project Success Index 2-Sample t-Test Results"*, the P-Value is less than 0.05. This indicates that there is a statistically significant difference between the means and the null hypothesis that states "Applying agile methodologies to heavy-civil bridge construction projects will not result in a better Project Success Index (PSI)" is rejected.

Two-Sample T-Test and CI: WPSI, APSI				
Method				
μ_1: Mean of WPSI	Equal variances are not assumed for this analysis.			
μ_2: Mean of APSI				
Difference: $\mu_1 - \mu_2$				
Descriptive Statistics				
Sample	N	Mean	StDev	SE Mean
WPSI	40	0.0606	0.0253	0.0040
APSI	40	0.0398	0.0174	0.0028
Estimation for Difference				
Difference	95% CI for Difference			
0.02081	(-0.01112, 0.03050)			
Test				
Null Hypothesis	H_0: $\mu_1 - \mu_2 = 0$			
Alternative Hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$			
T-Value	DF	P-Value		
4.28	69	0.000		

Figure 4-15. Project Success Index 2-Sample t-Test Results

4.7 Waterfall PPV and Agile PPV Data Analysis

Since the project data itself has been evaluated, we can perform the calculations to determine what the PPV values are, as detailed in Chapter 2.5. *Scoring Methods.* Once these are calculated, we can evaluate the project data sets for normal distribution. Considering Figure 4-16. *"Waterfall Project Performance Value Probability Plot*", the P-Value is greater than 0.05, proving the PPV distribution for waterfall projects is normal.

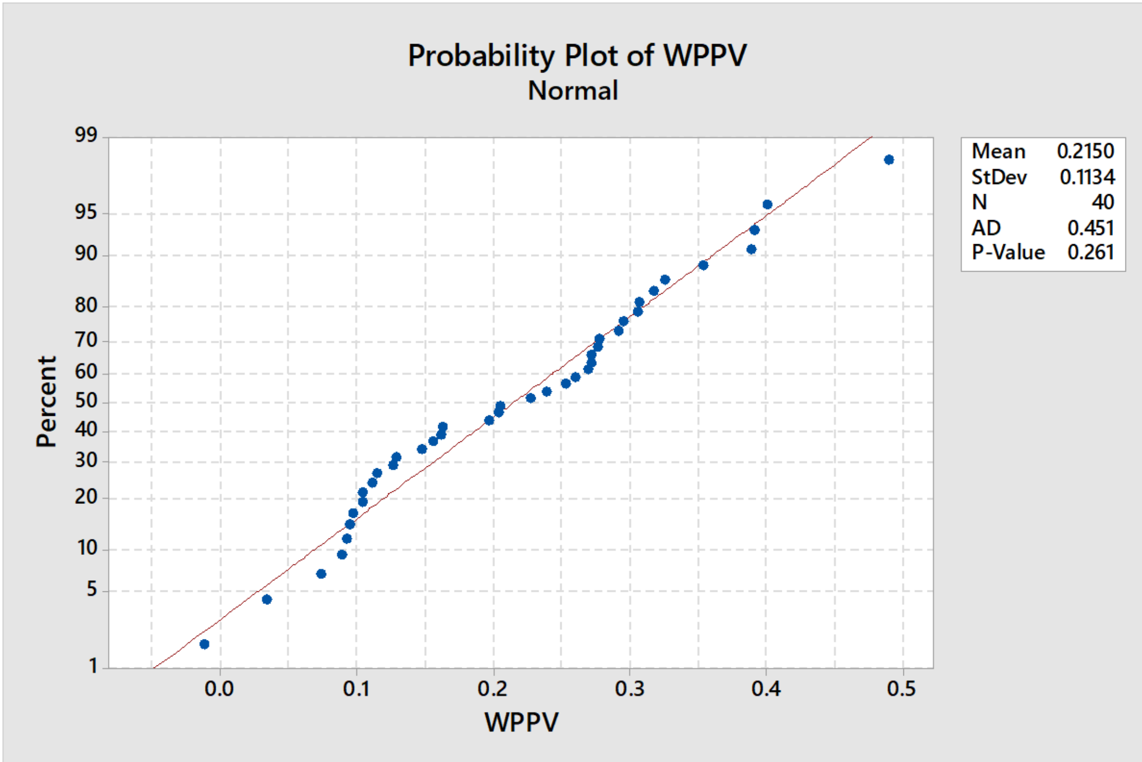

Figure 4-16. Waterfall Project Performance Value Probability Plot

Considering Figure 4-17. *"Agile Project Performance Value Probability Plot"*, the P-Value is greater than 0.05, proving the PPV distribution for agile projects is normal. This is another instance of a good data set with no zero-value data points identified.

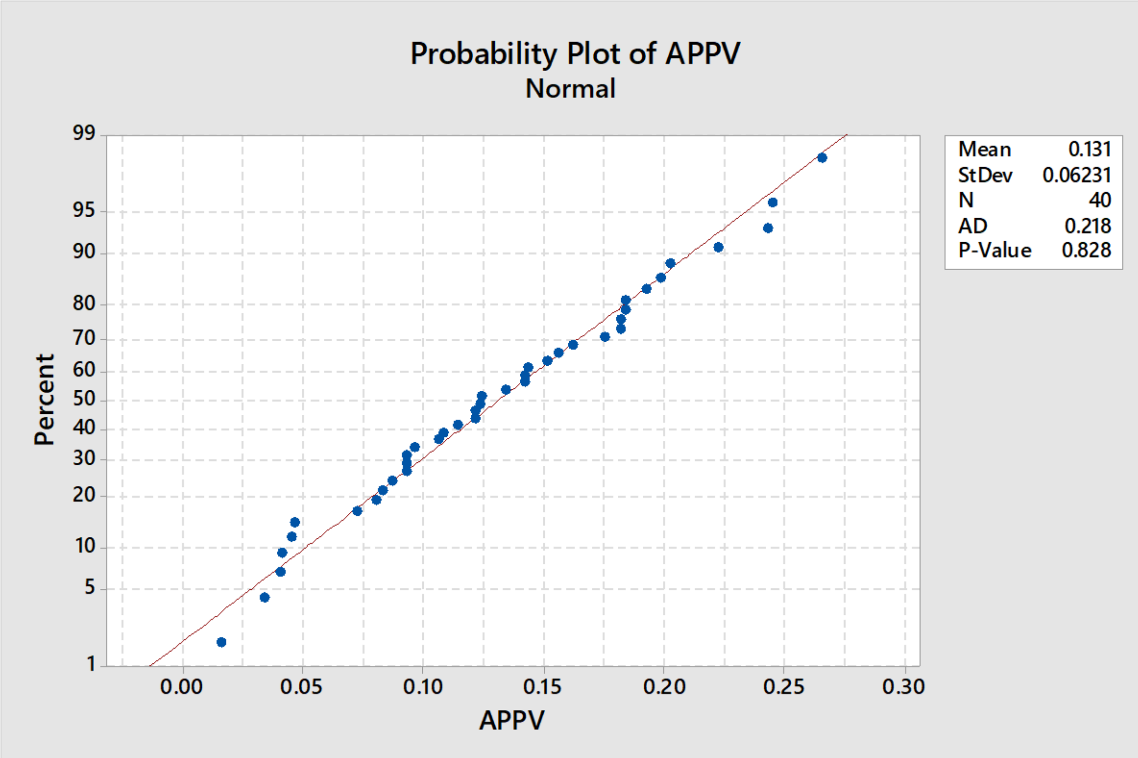

Figure 4-17. Agile Project Performance Value Probability Plot

Since the data sets shown in both Figure 4-16. *"Waterfall Project Performance Value Probability Plot"* and Figure 4-17. *"Agile Project Performance Value Probability Plot"* are normally distributed, then the data can be compared using the 2-Sample t-Test to see if there is a significant difference between the means of the two Project Performance Value data sets. Tests were conducted using Minitab 2018 and as found in Figure 4-18. *"Project Performance Value 2-Sample t-Test Results"*, the P-Value is less than 0.05. This indicates that there is a statistically significant difference between the means and the null that states "Applying agile methodologies to heavy-civil bridge construction projects will not result in a better Project Performance Value (PPV)" is rejected.

<table>
<tr><th colspan="6">Two-Sample T-Test and CI: WPPV, APPV</th></tr>
<tr><td colspan="6">Method</td></tr>
<tr><td colspan="2">μ_1: Mean of WPPV</td><td colspan="4" rowspan="3">Equal variances are not assumed for this analysis.</td></tr>
<tr><td colspan="2">μ_2: Mean of APPV</td></tr>
<tr><td colspan="2">Difference: μ_1 - μ_2</td></tr>
<tr><td colspan="6">Descriptive Statistics</td></tr>
<tr><td>Sample</td><td>N</td><td>Mean</td><td colspan="2">StDev</td><td>SE Mean</td></tr>
<tr><td>WPPV</td><td>40</td><td>0.215</td><td colspan="2">0.1130</td><td>0.0180</td></tr>
<tr><td>APPV</td><td>40</td><td>0.131</td><td colspan="2">0.0623</td><td>0.0099</td></tr>
<tr><td colspan="6">Estimation for Difference</td></tr>
<tr><td colspan="2">Difference</td><td colspan="4">95% CI for Difference</td></tr>
<tr><td colspan="2">0.084</td><td colspan="4">(0.0431, 0.1249)</td></tr>
<tr><td colspan="6">Test</td></tr>
<tr><td colspan="3">Null Hypothesis</td><td colspan="3">H_0: $\mu_1 - \mu_2 = 0$</td></tr>
<tr><td colspan="3">Alternative Hypothesis</td><td colspan="3">H_1: $\mu_1 - \mu_2 \neq 0$</td></tr>
<tr><td colspan="2">T-Value</td><td>DF</td><td colspan="3">P-Value</td></tr>
<tr><td colspan="2">4.1</td><td>60</td><td colspan="3">0.000</td></tr>
</table>

Figure 4-18. Project Performance Value 2-Sample t-Test Results

4.8 Waterfall PSI and Waterfall PPV Data Analysis

We know from Chapter 4.6 *"Waterfall Project Success Index and Agile Project Success Index Data Analysis"* and Chapter 4.7 *"Waterfall Project Performance Value and Agile Project Performance Value Data Analysis"* that the data for each set is normally distributed. Therefore, we only need to look at the 2-Sample t-Test to evaluate whether or not the means of each data set considered are statistically similar.

Before we can do this, however, we need to adjust the scores of one data set by introducing a constant multiplier so a like-by-like comparison can be evaluated properly. This is required to remove the factoring of data done by the PSI scoring method. In this case, the PSI values were adjusted as shown:

Waterfall Data: Waterfall Average PSI = 0.0614

Waterfall Average PPV = 0.215

W - Multiplier Average PPV/PSI = 3.502

Agile Data: Agile Average PSI = 0.0398

Agile Average PPV = 0.131

A - Multiplier Average PPV/PSI = 3.291

Considering these new data sets, we first evaluate the adjusted values for normality as follows:

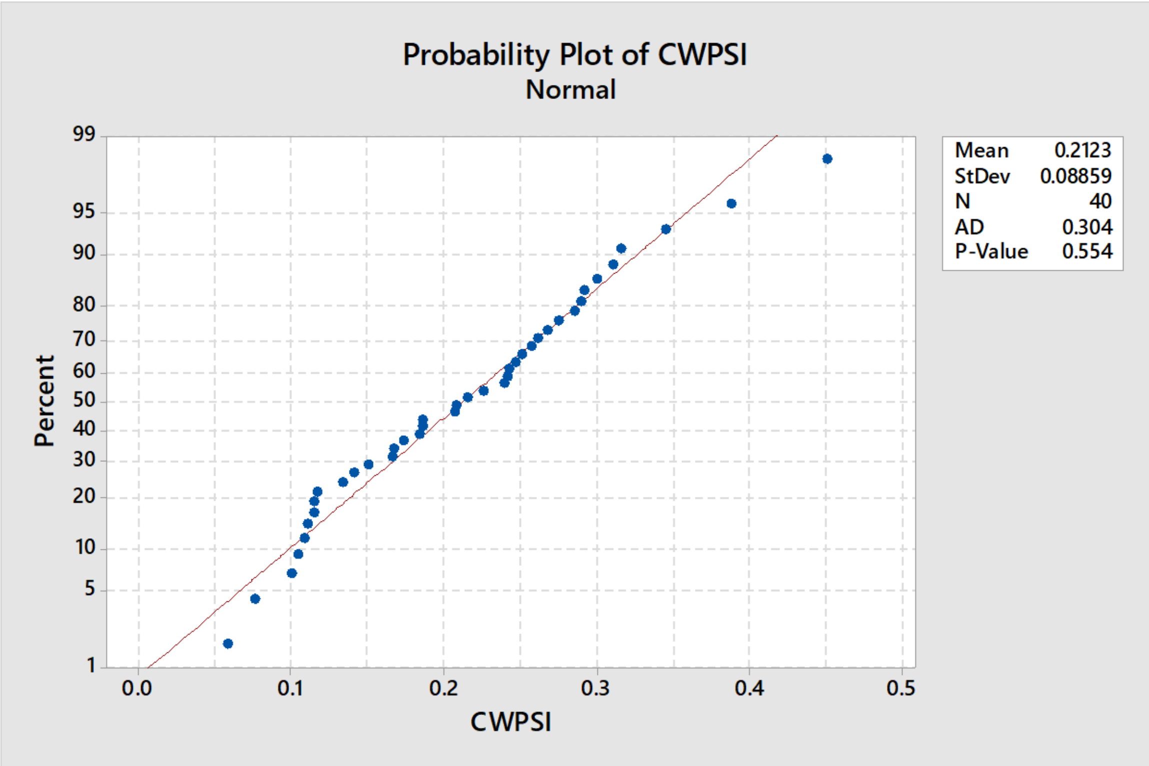

Figure 4-19. Corrected Waterfall Project Success Index Probability Plot

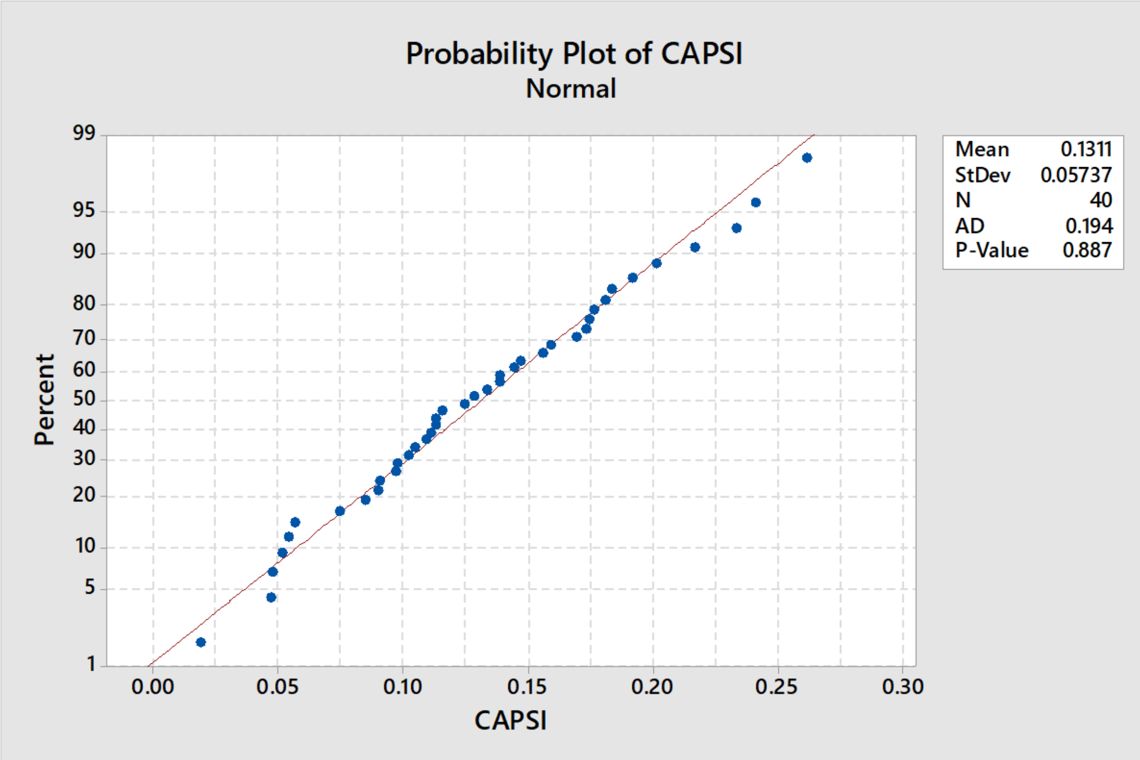

Figure 4-20. Corrected Agile Project Success Index Probability Plot

As shown in Figure 4-19. *"Corrected Waterfall Project Success Index Probability Plot"*, the plot reveals that the Corrected Waterfall Project Success Index data is normally distributed (P-Value > 0.05). Similarly, the Corrected Agile Project Success Index data set is also normally distributed (See Figure 4-20. *"Corrected Agile Project Success Index Probability Plot"*). At this point, the 2-Sampled t-Test can be used to evaluate the data sets.

As such, tests were conducted using Minitab 2018 and as found in Figures 4-21. *"Waterfall PPV vs Corrected Waterfall PSI 2-Sample t-Test Results"* and 4-22. *"Agile PPV vs Corrected Agile PSI 2-Sample t-Test Results"*, the P-Values are both greater than 0.05. This indicates that there is not a statistically significant difference between the means. In other words, the null that states "Comparing the Project Performance Value

(PPV) to the Project Success Index (PSI) results in statistically similar scoring values" cannot be rejected. This shows that the Project Performance Value method of scoring and the Project Success Index method of scoring are statistically similar and can be used in place of each other with high probability of accurate evaluation.

Two-Sample T-Test and CI: WPPV, CWPSI				
Method				
μ_1: Mean of WPPV		**Equal variances are not assumed for this analysis.**		
μ_2: Mean of CWPSI				
Difference: $\mu_1 - \mu_2$				
Descriptive Statistics				
Sample	**N**	**Mean**	**StDev**	**SE Mean**
WPPV	40	0.2150	0.1130	0.0180
CWPSI	40	0.2123	0.0886	0.0140
Estimation for Difference				
Difference		**95% CI for Difference**		
0.0026		(-0.0427, 0.0480)		
Test				
Null Hypothesis			**H_0: $\mu_1 - \mu_2 = 0$**	
Alternative Hypothesis			**H_1: $\mu_1 - \mu_2 \neq 0$**	
T-Value		**DF**	**P-Value**	
0.12		73	0.908	

Figure 4-21. Waterfall PPV vs Corrected Waterfall PSI 2-Sample t-Test Results

Two-Sample T-Test and CI: APPV, CAPSI				
Method				
μ_1: Mean of APPV	**Equal variances are not assumed for this analysis.**			
μ_2: Mean of CAPSI				
Difference: $\mu_1 - \mu_2$				
Descriptive Statistics				
Sample	**N**	**Mean**	**StDev**	**SE Mean**
APPV	40	0.1310	0.0623	0.0099
CAPSI	40	0.1311	0.0574	0.0091
Estimation for Difference				
Difference	**95% CI for Difference**			
0.0001	(-0.0267, 0.0266)			
Test				
Null Hypothesis	**H_0: $\mu_1 - \mu_2 = 0$**			
Alternative Hypothesis	**H_1: $\mu_1 - \mu_2 \neq 0$**			
T-Value	**DF**	**P-Value**		
0	77	0.996		

Figure 4-22. Agile PPV vs Corrected Agile PSI 2-Sample t-Test Results

4.9 Summary

To summarize the information provided in this chapter regarding the statistical analysis approach discussed earlier, we look to Table 4-12. *"Distribution Summary"* and Table 4-13. *"Test Summary"*.

Source	Data	Distribution	Test Type
Waterfall	Cost	Normal	2-Sample t-Test
	Schedule	Non-Parametric	Mann-Whitney
	Quality	Non-Parametric	Mann-Whitney
	Safety	Non-Parametric	Mann-Whitney
	PSI	Normal	2-Sample t-Test
	PPV	Normal	2-Sample t-Test
	CPSI	Normal	2-Sample t-Test
Agile	Cost	Normal	2-Sample t-Test
	Schedule	Non-Parametric	Mann-Whitney
	Quality	Non-Parametric	Mann-Whitney
	Safety	Non-Parametric	Mann-Whitney
	PSI	Normal	2-Sample t-Test
	PPV	Normal	2-Sample t-Test
	CPSI	Normal	2-Sample t-Test

Table 4-12. Distribution Summary

Sources	Data	Test Type	Null	Result
Waterfall vs. Agile	Cost	2-Sample t-Test	Cannot Reject	Not Statistically Different
	Schedule	Mann-Whitney	Reject	Statistically Different
	Quality	Mann-Whitney	Reject	Statistically Different
	Safety	Mann-Whitney	Cannot Reject	Not Statistically Different
	PSI	2-Sample t-Test	Reject	Statistically Different
	PPV	2-Sample t-Test	Reject	Statistically Different
Waterall	WPPV vs CWPSI	2-Sample t-Test	Cannot Reject	Not Statistically Different
Agile	APPV vs CAPSI	2-Sample t-Test	Cannot Reject	Not Statistically Different

Table 4-13. Test Summary

After evaluating the data and reviewing the 7 research questions and hypotheses, the results show that 2 of the 4 KPI data sets (RQ2: Schedule and RQ3: Quality) revealed statistically different results between those projects that used agile methods versus those that didn't. The other 2 KPI's (RQ1: Cost and RQ4: Safety) did not. Further, the comparison of the scoring methods (RQ5: PSI and RQ6: PPV), both yielded results that were statistically different, leading to the hypothesis (H5 and H6) that using agile management approaches on construction projects does produce better efficiency and delivery. This means that the simple introduction of a few agile approaches can have a great impact on most projects. Lastly, the data set for RQ7 (PSI = PPV), yielded results that the scoring methods were both similar and interchangeable. A more in depth discussion and final conclusions will be presented in Chapter 5 *"Discussion and Conclusions"* and in it, all values, tests, and findings along with conclusions and recommendations for further studies will be brought forth.

Chapter 5—Discussion and Conclusions

"Arming employees with the tools, know-how, and mindset needed to successfully innovate on a continual basis will be paramount to organizational survival."

- Kaihan Krippendorff

5.1 Introduction

In order to evaluate the data test results adequately, it's important to consider each Key Performance Indicator separately (RQ1 through RQ4). Once complete, we will look at their effects as a whole when we evaluate the Project Success Indices (RQ5) and the Project Performance Values (RQ6), and finally we will look at the effectiveness of the Project Performance Value vs. the Project Success Index (RQ7) and how the PPV approach can benefit the end user.

5.2 Waterfall vs. Agile Costs

These values revealed a linear, normally-distributed data set for both the agile data and the waterfall data. Looking at the graphical data, it is clear that the added costs, as discussed in Chapter 2.4.1 "Cost" have a linear relationship with the overall value of the project. It is extremely difficult to predict when a supplier isn't going to deliver the correct materials or when a piece of equipment is going to break down. Likewise, subcontractors are notorious for not meeting expectations, causing undue costs and issues on projects on a normal basis.

As we look at the data sets, the facts show that on average, the waterfall value for cost in this case is $75,600.00 while costs associated with the agile-managed projects is $72,100.00. This is a savings of $3,500.00, although small, still a savings overall. The statistical analysis in both cases revealed normal distribution, but failed to reject the null hypothesis that the means were statistically different.

Considering the plain-sight value along with the statistical analysis, it is clear that the mean values of cost, as shown, do not reveal any significant improvement by using agile methodologies vs. those traditional methods found in the waterfall cases. My final analysis here is that agile methodologies do not improve costs associated with variations, changes, subcontractors, suppliers, and equipment issues.

Agile vs Waterfall Cost: No Improvement

5.3 Waterfall vs Agile Schedule

The values associated with schedule issues were found to be non-parametric, resulting in the use of the Mann-Whitney analysis method for non-parametric datasets. Considering that these values as graphed in Chapter 4.3 "*Waterfall Schedule and Agile Schedule Data Analysis"* have multiple zero values indicates that there is not a normality associated with the overall contract values and therefore, leads one to believe that agile management techniques could have a positive effect. With anything, thorough planning and attention to detail can always improve a schedule and help to meet the requirements set forth in meeting the timelines. There is always room to improve.

As the data shows numerically, the averages reflect significant financially-based schedule improvements between waterfall practices and agile methods. In fact, the waterfall average for schedule is $89,300.00 while the average found for agile project is $30,800.00, meaning that with respect to schedule costs for the data evaluated, realized costs were 3 times higher for waterfall projects than they were for agile. Using agile in this case presents a significant financial reduction in value of 65.5%. Considering the statistical analysis, we find both datasets non-parametric and when compared, we can reject the null, meaning the medians of both data sets are significantly different.

Reviewing the clear financial improvement from the data, coupled with the statistical indication that there is a significant difference between the medians, it should be obvious that there is a marked improvement in using agile methodologies when it comes to evaluating the schedule.

Agile vs Waterfall Schedule: Improvement

5.4 Waterfall vs Agile Quality

The values associated with quality issues were also found to be non-parametric, resulting in the use of the Mann-Whitney analysis method for non-parametric datasets. Considering that these values, as graphed in Chapter 4.4 "*Waterfall Quality and Agile Quality Data Analysis",* have multiple zero values indicates that there is not a normality associated with the overall contract values and therefore, leads one to believe that proper inspection and oversight of the work could have a positive effect. Quality is important for project success and must have a diligent workforce for inspection and proper management practices to ensure that all action items are being properly inspected, checklists are being used, documentation and pictures are consistent, and work is being watched from start to finish. Not everything can be caught, but with an engaged quality team, issues can be minimalized.

As the data shows, the averages reflect improvements between waterfall practices and agile methods when it comes to quality. Looking at the data, we can see the waterfall average is $31,700.00 while the average found for agile projects is $12,600.00. This is a significant reduction in cost at a saving of 60.3%. Considering the statistical analysis, we find both datasets non-parametric and when compared, we can reject the null, meaning the medians of both data sets are statistically significantly different.

Considering the clear improvement from the quality data, coupled with the statistical indication that there is a significant difference between the medians, it should be obvious that there is a marked improvement in using agile methodologies when it comes to the quality of the project.

Agile vs Waterfall Quality: Improvement

5.5 Waterfall vs Agile Safety

The values associated with safety issues were also found to be non-parametric, resulting in the use of the Mann-Whitney analysis method for non-parametric datasets. Considering that these values, as graphed in Chapter 4.5 "*Waterfall Safety and Agile Safety Data Analysis"* having multiple zero values, indicates that there is not a normality associated with the overall contract values and therefore, leads one to believe that proper oversight and focused safety management of the crews could have a positive effect. It is important when it comes to safety to have a diligent workforce for inspection and proper management to ensure that all actions are being monitored, there is proper training of all personnel, and there is always a high level of situational awareness on the jobsite. Anything less is simply not acceptable. With this type of engaged focus, one would expect improvement across the board on any project.

This is not the case when it comes to the data, as shown, however. Although there is some difference between the averages when comparing the waterfall method to those found in agile project management, it is not statistically significant. As the data shows numerically, the averages do reflect improvements between waterfall practices and agile methods when it comes to safety. Looking at the data, we can see the waterfall average for safety is $18,500.00 while the average found for the agile projects is $15,700.00. This is a reduction in cost of 20.5%. When we look at the statistical analysis, however, we cannot reject the null, meaning the medians of both data sets are not significantly different. I suspect the test results may be skewed due to the high zero-value count in the data sets, meaning there are multiple projects that did not have lost-time accidents. In fact, of all the cases where the data was not normal, safety had median values of zero. I suspect this could be why the data analysis resulted in not being able to reject the null hypothesis. Further study of the effects of zero values in data sets for these Key Point Indicators may be beneficial to the field.

Considering the safety data statistical analysis alone, we simply cannot claim there to be an indication that there is a significant difference between the medians. This leads us to not being able to reject the null hypothesis. It appears that safety issues are also not statistically affected by the use of agile methods, but I suspect further study into safety and agile methods may prove differently.

Agile vs Waterfall Safety: No Improvement

5.6 Waterfall PSI vs Agile PSI

The values associated with the Project Success Index data were found to be normally distributed. As such, we used the 2-Sample t-Test for testing. Reviewing the data at face value, we can see that there is an improvement when scoring the data from waterfall projects compared to that found in the agile dataset. The waterfall data yielded a Project Success Index score of 0.061, while the agile data had a score of 0.0398. This is a numerical improvement of 34.8%.

After performing the statistical testing, as found in Chapter 4.6 *"Waterfall PSI and Agile PSI Data Analysis"*, we see normal distribution indicators and test results that show there is cause to reject the null. Considering the Project Success Index data statistical analysis, we can claim there is a significant difference between the means. It appears that there is an improvement shown by the Project Success Index scoring method and that the projects in the datasets revealed a statistical improvement.

Agile vs Waterfall PSI: Improvement

5.7 Waterfall PPV vs Agile PPV

The values associated with the Project Performance Value data were found to be normally distributed. As such, we used the 2-Sample t-Test for testing. Reviewing the data at face value, we can see that there is an improvement when scoring the data from waterfall projects compared to that found in the agile dataset. The waterfall data yielded a Project Performance Value of 0.215, while the agile data had a Project Performance Value of 0.131. This is a numerical improvement of 39.1%.

After performing the statistical testing, as found in Chapter 4.7 *"Waterfall PPV and Agile PPV Data Analysis"*, we see normal distribution indicators and test results that show there is cause to reject the null. Considering the Project Performance Value data statistical analysis, we can claim there to be an indication that there is a significant difference between the means. It appears that there is an improvement shown by the Project Performance Value scoring method and that the projects in the datasets revealed a statistical improvement by the use of agile methods.

Agile vs Waterfall PPV: Improvement

5.8 PPV vs. PSI

The values associated with the Project Success Index data and those found for the Project Performance Value data were found to be normally distributed, as stated above. As such, we used the 2-Sample t-Test for testing. In this case, reviewing the data at face value yields little for the sake of conclusions. The values of the Project Success Index are weighted, while those found for the Project Performance Values are not. Constants were used, as described in Chapter 2.5 *"Scoring Methods"* in order to compare like data, but the only way to really confirm the compatibility of the 2 methods is through statistical analysis. As such, we see normal distribution indicators and test results that show there is no cause to reject the null. Considering this, we must accept that the mean values are statistically similar, and the data reflects that there is no statistically significant difference between the two scoring methods.

PPV vs PSI: No Difference

5.9 Conclusion

Overall, this has been a uniquely challenging project. From gathering the data, to researching where the gaps were in the literature, codifying the dataset and getting it into form for proper analysis, performing the analysis, and finally presenting the data with conclusions has been an awesome adventure. Through all of this, I can safely say that, although using agile methodologies may not impact all aspects of construction and its Key Performance Indicators, it did positively improve for the data set evaluated here with respect to the scoring methods used and revealed great improvements in the scheduling and quality aspects of a typical heavy-civil construction project.

Overall Agile Methodologies vs Waterfall: Improvement

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