Best Practices from WisDOT Mega and ARRA Projects - Statistical Analysis and % Time vs. % Cost Metrics

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Justin Kavanaugh
Gary Whited

Construction and Materials Support Center
University of Wisconsin – Madison

Executive Summary

This study was undertaken to: 1) apply a benchmarking process to identify best practices within four areas Wisconsin Department of Transportation (WisDOT) construction management and 2) analyze two performance metrics, % Cost vs. % Time, tracked by the WisDOT on American Recovery and Reinvestment Act (ARRA) projects to develop benchmarks for highway construction. The first objective involved an in-person survey of senior department staff and other experienced project managers. Survey data was collected for 45 best practices, scored, and then ranked based on three categories: general, small budget ARRA, and large budget 'Mega' projects. The second research object utilized the performance metrics of percent complete by time and percent complete by cost to generate a cumulative process curve, or S-curve. Monthly data points were collected for 283 WisDOT ARRA projects constructed in 2009 and 2010.

Results from the best practice survey provide nine general best practices with two additional best practices, one for large scale mega-type projects and one for smaller scale ARRA-type projects. Additionally, survey results showed high agreement for the top 10 best practices that were consistent across the three categories. Results from the % Time vs. % Cost study were used to generate cumulative process curves that were then compared to prior research on electrical/mechanical construction projects. Based upon regression analysis, it was discovered that heavy construction projects tended to have much flatter, more linear, S-curves when compared to electrical/mechanical projects. Knowledge of the expected cumulative process curve allows the project management team to quickly compare their observed project performance in terms of expenditures versus earned time to the

benchmarked metrics of this study. Such a method would be a convenient method of predicting the occurrence, but not magnitude, of budget and schedule overruns.

In sum, the combined use of effective best practices and control points can help to reduce the frequent occurrence of budget and schedule overruns on transportation projects. Reducing waste will help to add value by allowing a greater number of projects to be funded and constructed, which in turn will help to relief stress on the current transportation infrastructure.

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CHAPTER 1

INTRODUCTION

1.1 PROBLEM CONTEXT

In 2009, a study was commissioned by the Policy Research Program of the Wisconsin Department of Transportation (WisDOT) to identify program level best practices. The Construction Material Support Center (CMSC) at the University of Wisconsin-Madison was asked to identify and evaluate the procedures, standards and programs in use on WisDOT "Mega" projects and ARRA projects that demonstrate the greatest potential benefit to the department. The Federal Highway Administration (FHWA) defines a 'mega' project as a project having a construction budget greater than $500 million or being of sufficient complexity and heightened public scrutiny as to require additional risk mitigation methods for budget and schedule. In contrast, construction projects partially or wholly funded through the American Recovery and Reinvestment Act of 2009 (ARRA) were of a much smaller scale and budget but had mandatory federal requirements of cost and schedule tracking to foster transparency and accountability of funding.

The research effort began with a preliminary project scoping meeting involving key WisDOT personnel experienced in delivery of Mega projects. This preliminary meeting identified a wide range of potential topic areas to be included in the research study. However, to maintain a manageable work scope, the best practice study would focus only on four areas of the construction process: 1) Project management with benchmarking and metrics, 2) Project change management, 3) Document control and reporting, and 4) Financial Reporting. These four areas of construction were selected because they captured the majority of the new processes, methods, and procedures that were currently being implemented for Mega and ARRA WisDOT projects.

While all four construction areas will be addressed in this study, the bulk of the research will be on benchmarking and metrics and financial reporting, areas one and four respectively. This paper takes a deeper look into the use of performance measures, how performance measures can be used to create benchmarks, and how the benchmarking process is used to select only the most appropriate best practices. Additionally, the research presents data from a qualitative survey study on best practices and their perceived value. Finally, best practices relating to benchmarking, financial reporting, and earned value analysis will be quantitatively assessed using data gathered and stored as part of the ARRA process on WisDOT transportation construction projects.

1.2 PROBLEM STATEMENT

1.2.1 The construction budget problem

A 2007 report collected voluntary construction phase data from 20 states over a five year period from 2001 to 2005 (American Association of State Highway and Transporation Officials, 2007). In total, nearly 27,000 projects were submitted for the study. The study found that 54% of projects with budgets less than $5 million overran their original budget, with 19% of those projects overrunning the budget by more than 10% of the original award amount. For project greater than $5 million, the study found that 82% of those projects overran their budgets, with 30% of those projects being over by more than 10% of the original budget.

It would appear that a trend exists, the larger a project's budget the greater the chance of a cost overrun and also the greater the magnitude of the overrun. Moreover, even worse statistics are apparent when looking at the performance of a project during the implementation stage, the period from project approval through the end of construction. A recent research study showed that 90% of transportation infrastructure projects experience cost escalation of construction costs during the implementation stage, with an average escalation amount of 20% from the original budget (Flyvbjerg, Holm, & Buhl, 2004). There is clearly a major problem and dilemma at work here; more and more mega projects with mega-size budgets are being planned and built only to be burdened with the likelihood of budget overruns.

The realization that only half of transportation projects will finish on or under budget should be unsettling to both the state highway agency (SHA) and the public alike. However, what is truly alarming and counter-intuitive in an era of advancing technology, is that cost escalation during the project implementation phase has actually been *increasing* in degree for the past 70 years (Flyvbjerg et al., 2004). Unmistakably something is amiss and lessons are not being learned the first time around.

1.2.2 Current state of transportation infrastructure

The effect of budget and schedule overrun on a single project has global effects on the entire SHA project program budget. Keeping project construction on-time and on-budget allows the SHA to deliver both a greater number of projects and in less time (AASHTO, 2007). Over-budget projects only act to deplete the SHA's fixed annual budget, resulting in either reduction in project scope or elimination altogether. Either way the public users of the transportation network, as taxpayers, lose out by having increased taxes, fewer infrastructure improvement projects, and an increased commute time as construction exceeds the original timeline.

If past and present project performance is any indication of what is to come, there will be serious repercussions to an already fragile, over-burdened transportation infrastructure. Current estimates suggest that 32% of the nation's major roadways are in poor to mediocre condition and that 24% of America's bridges are structurally deficient (Roads and Bridges Fact Sheet). Road conditions are so poor that the American Society of Civil Engineers (ASCE) has consistently rated the integrity of the nation's roadway infrastructure system at a failing grade of a "D-" (ASCE Roads Fact-Sheet, 2009). The 2009 ASCE Report Card also projected that only 41% of the $930 billion needed over the next 5-year period would be invested, and that figure is for roads and bridges alone and already takes into account the $27.5 billion in funding from ARRA (ASCE Infrastructure Reportcard, 2009). By comparison, the 2009 capital investment in new highway construction was only $71 billion (FHWA). Additionally, it is estimated that $78 billion is lost in fuel consumption and productivity each year by U.S. motorists stuck in traffic (ASCE Roads Fact-Sheet, 2009). With the average SHA annual budget near $3 billion, significant dollar savings can be realized from modest financial reductions of only 1% to 2%. Given the current drought of funding for such roadway projects, it is imperative that any available dollars be maximized to their fullest potential. However, in its present state of frequent construction budget overruns, this will never be the case.

To make matters worse, a 2010 national census reported that car owners in the United States are estimated to drive three trillion miles each year (Roads and Bridges Fact Sheet), and on the already poor and deteriorating transportation network (Figure 1).

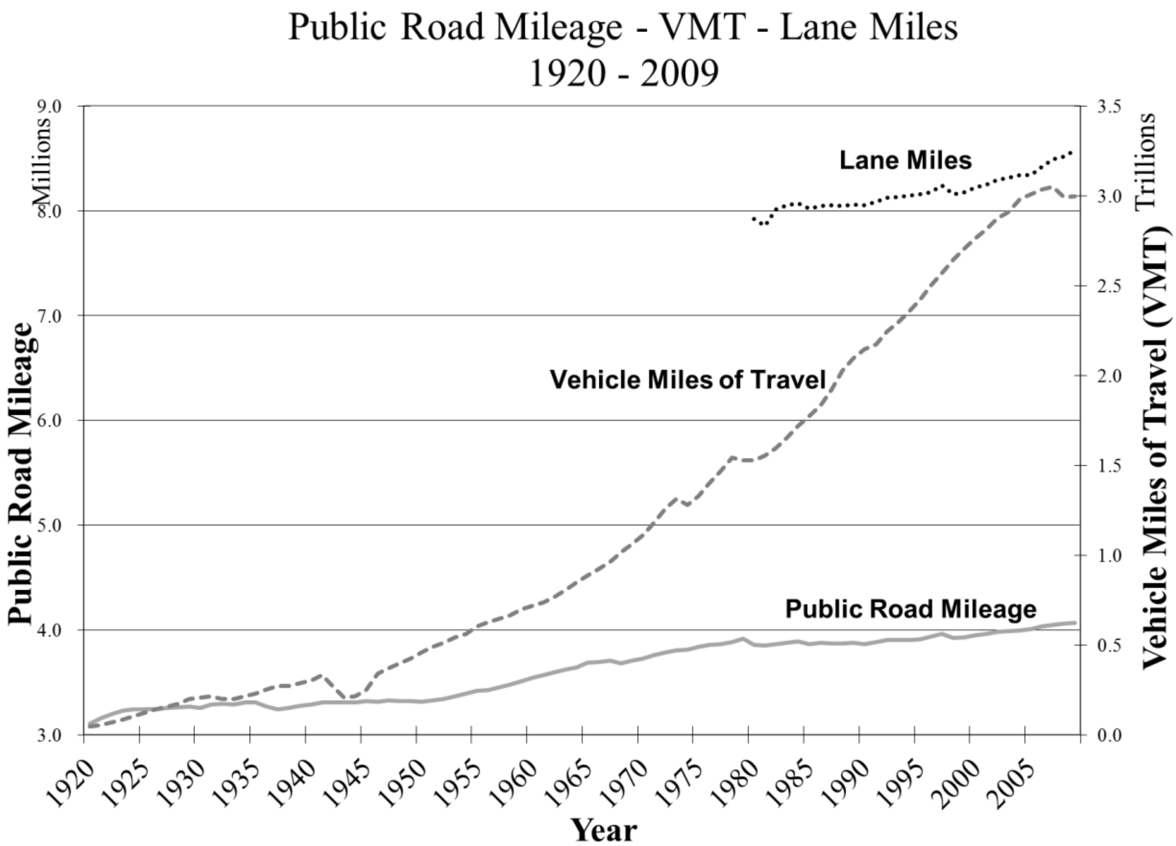


Figure 1: Vehicle roadway usage trends, adapted from FHWA archive data (FHWA)

The increasing influx of traffic volume into the roadway network further reduces the life span of the network to well below its original design, thus accelerating the need for repairs. The consequences of operating vehicles on these failing roadways and bridges go beyond the obvious public safety concerns. As was reported earlier, poor road conditions exacerbate the financial pressures on the public by decreasing fuel efficiency and also productivity.

Whatever the solution to improving the roadway network in the United States may be, it will undoubtedly require a concerted and substantial investment in the Nation's roadway network. However, finding additional funding would be difficult. Alternatively, a solution may lie in becoming better at how SHAs can extract the greatest amount of value on a per dollar basis by improving their processes.

1.2.3 Moving Forward

Avoiding budget overruns on construction projects is a multi-faceted problem. Good planning requires accurate knowledge of the cost and schedule requirements of both large and small projects. Another aspect required of good project planning is early detection of risks associated with project overruns. It is accepted knowledge that the cost associated with making changes to a project exponentially increases as the project progresses (Figure 2).

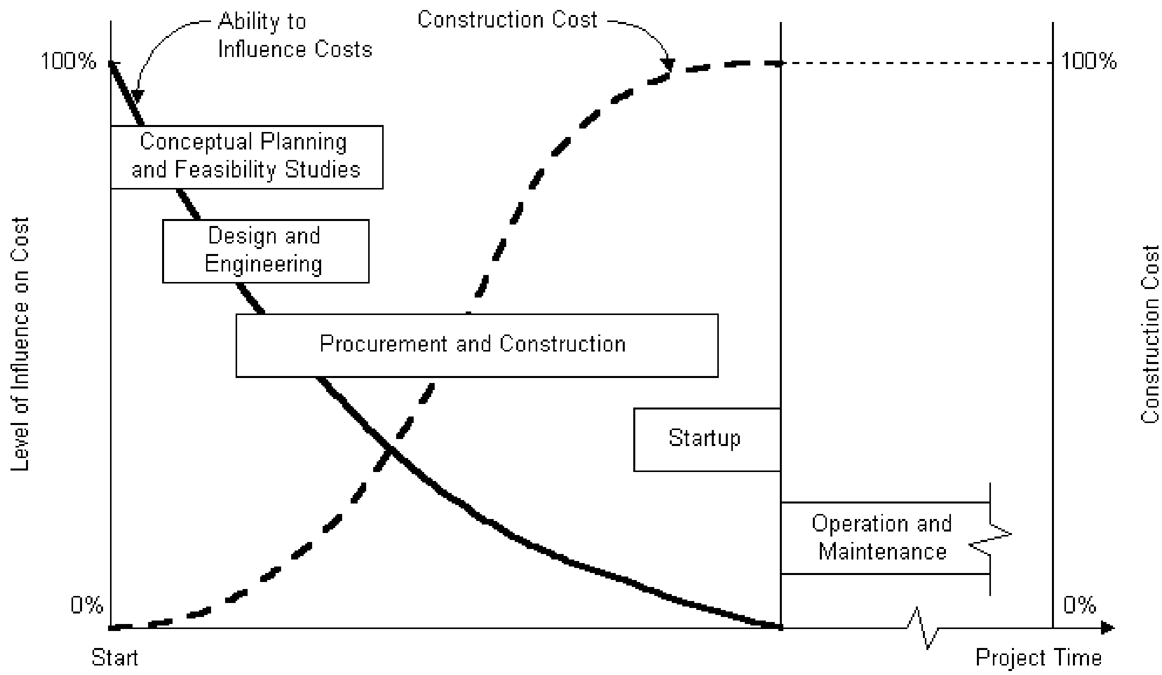


Figure 2: Ability to influence construction cost over time (Hendrickson & Au, 1989)

Therefore, if changes or corrective action are to be made on a project, they should be done as early as possible. Early issue detection on a project allows the management team to formulate a proper response that minimizes the cost impact to the project budget. While certain scenarios such as differing site conditions cannot be reasonably foreseen, there are proven tools that provide the management team with the ability to forecast budget and schedule overruns ahead of time. The benchmarking process allows for identification of these tools.

1.3 RESEARCH OBJECTIVES

This study has two primary objectives: 1) identify and evaluate those best practices that have the greatest benefit to WisDOT and 2) use quantitative data from WisDOT ARRA projects to evaluate two specific best practices: implementing benchmarking performance measures and financial reporting.

1.4 RESEARCH SCOPE

As mentioned previously, this research study limited its scope to best practices in the four construction areas of: 1) Project management with benchmarking and metrics, 2) Project change management, 3) Document control and reporting, and 4) Financial Reporting. Furthermore, this study was commissioned by WisDOT all the all quantitative data came from WisDOT projects constructed in 2009 and 2010 as part of the ARRA program.

1.5 RESEARCH METHODOLOGY

To aid in the first research objective, best practices will be identified from several sources: the WisDOT Construction and Material Manual (CMM), the Construction Management Plan for both the Marquette Interchange (completed 2008) and I-94 North-South Corridor (currently under construction) mega projects, and also from CMSC expert staff (CMM, 2010) (I-94 CMP, 2010) (Marquette Interchange CMP, 2005). Next, key DOT and state personnel will be interviewed to identify which of those best practices they feel are most important. This best practices workshop will involve a mixture of WisDOT, FHWA and state consultants and will be held in early 2011 to provide subjective evaluation of the best practices developed by the CMSC. Qualitative responses from that survey will allow the CSMS research staff to rank best practices on several categories as well as perform correlation tests.

The second research objective was based upon using the extensive ARRA project tracking database maintained by WisDOT. From this database, multiple variables were selected, plotted, and analyzed using spreadsheet software and the R statistics package. Projects were placed into different categories based on such variables as region, contract amount, contract duration, and contract type (structures vs. non-structures). Also, a regression analysis was used to generate best fit models for percent complete by time vs. percent complete by cost for each category. Statistic testing between linear and non-linear regression models were used to indicate which model best explains the observed data. Lastly, control points at regular time intervals during the construction process were developed and compared with control points from other trade construction.

1.6 REVIEW

Clearly there is a need to reduce the frequency of budget and schedule overruns on transportation construction projects. In its current state, transportation improvement funds may not be being used to their maximum potential. The next chapter will provide review of the research literature on ways to improve project performance in terms of budget and schedule.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This literature review will cover three topic areas. First, there will be an in-depth look into performance measures, benchmarks, and the benchmarking process. Second, the application of benchmarks to two types of roadway construction project will be investigated. Lastly, one particular best practice will be highlighted and further scrutinized in later chapters.

2.2 PERFORMANCE MEASURES AND BENCHMARKING

2.2.1 Introduction

At its core, a SHA is still a business that operates under the familiar concepts of costs and revenues. Also, the competitive drive is present within a SHA, perhaps more than ever. Given the tight economic times, government agencies are increasingly being held accountable for their budgets and the public is demanding transparency and explanation of programs. Thus, there is a very real incentive for a SHA have a vested interest in being the best of the best among its competitors.

The next several sections will take a logical, step-wise look into how a SHA, or any business, can improve its performance and increase value in its construction projects. The first section will address how and why a business process can and should be quantified through the use of performance measures. Also the elements of performance measures as well as purposes for using them will be explained. The next section will look at the interconnections between the performance measure and the benchmark. Lastly, a summary of the process of benchmarking will be discussed along with common misconceptions of what benchmarking is and what it is not.

2.2.2 Use of Performance Measures

While any business practice could be benchmarked, it makes sense to only focus on those practices that are the best and most relevant to the business. Additionally, a well-crafted benchmark study will both identify what the benchmark is as well as how it will be realized (Camp, 1989). Moreover, after deciding on what practices should be measured, then next step is to create a system capable of measuring the performance of these practices. Using performance measures in benchmarking is one of the three primary types of benchmarking (Bogan & English, 1994). As its name suggests, performance benchmarking relies on the use of performance measures, which include such items as cost, time, productivity, delay, change orders, and other variables that are critical to successful business operations.

When dealing in the public sector, often times the public citizens demand evidence of a program's effectiveness. Furthermore, management within public agencies often wishes to compare performance among their industry counterparts. Indeed, the public manager's sole true purpose is to improve performance (Behn, 2003); which is the fundamental purpose of performance measurement (Hatry, 1999). In both cases, performance measurement also holds organizations accountable. Neither the act of measuring performance nor the data that is collected during measurement achieves anything by itself; rather it is only after someone applies what has been observed that anything is accomplished (Behn, 2003). Even the most reliable and accurate performance data is of little use to management if there is no clear understanding for how the data is to be used, or if the data is even appropriate for its intended use. Lastly, implementing performance measuring should not overextend the resources of the business, nor should a best practice over burden the individuals charged with its enforcement (Whited, Miller, & Grove, 2007).

2.2.3 Characteristics of Performance Measures

Robert Behn developed a list of eight purposes for using performance measures specifically for public business entities (Figure 3).

Figure 3: Eight purposes for measuring performance, adapted from (Behn, 2003)

Therefore Behn's eight purposes for performance measurement can be applied in the context of a public entity such as a SHA. A brief summary of each purpose is as follows (Behn, 2003):

- **Evaluate:** evaluation is the core basis for measuring performance. Furthermore, it allows tracking of project status and progression toward, or away, from set goals. However, evaluation cannot offer an explanation behind any improvements or shortcomings.
- **Control:** management must exert some form of control over its worker base; however, it is counterproductive to restrict a worker's behavior so much that it stifles creativity.
- **Purpose:** performance measurement facilitates the allocation of budgets. The poor performance of a program may be the result of under-funding. However, poor performance can be the result of other confounding factors (see "Learn" below).
- **Motivate:** performance measures can be used to learn how to perform better and to motivate the work base. Such motivation typically comes in the form of goal-setting.
- **Promote:** performance measures can be used to garner public support of programs that are successful and also to reveal programs that are failing.
- **Celebrate:** rewarding accomplishments tracked with performance measures fosters motivation within a group.
- **Learn:** in addition to evaluation, performance measures also create a means to learn the 'why' behind a program's failure or success.
- **Improve:** performance measures are not ends by themselves, but rather part of a circuitous feedback loop that drives improvement when properly implemented.

2.2.4 Developing Benchmarking Metrics

The foundation of the benchmarking process is the development of benchmarking metrics, or benchmarks. The concept of the benchmark is rather simple, and originates from the field of land surveying. A benchmark in a land survey serves as a reference datum from which elevations and distances between points of interest can be measured. A benchmark in business management is a practice translated into a quantifiable operational metric via performance measuring. A benchmark could be in terms of dollars, manpower, time expended, or any number of other quantifiable forms. Therefore, benchmarks are a quantitative means of measuring practices, and 'what gets measured gets managed,' and what gets managed can then be improved upon.

Christopher Bogan and Michael English define four key elements to designing successful benchmarks using performance measures: 1) measurement focus, 2) measurement perspective, 3) measurement control and 4) ability to collect data (Bogan & English, 1994).

- **Measurement Focus:** Identify value-adding and value-reducing processes or areas where performance is not meeting standards.
- **Measurement Perspective:** Benchmarks are either reactive, lagging indicators, or proactive, leading indication. A lagging indicator will only be able to provide perspective upon the completion of performance, whereas a leading indicator is capable of foreshadowing what is to come. From a risk management/business perspective, it will always be advantageous to become award of a problem or issue as

soon as possible. Any extra time that can be added to problem detection allows for greater risk management capability.

- **Measurement Control**: Benchmarks must be designed such that they capable of being executed at the level of the individual. According to Bogan et al., a benchmark should not strain the authority, responsibility, nor skills of those expected to work with the benchmark; chapter 3 will look at survey responses regarding ease or implementation for 45 different benchmarks.
- **Ability to Collect Data:** Data collection is a necessary part of creating a functional benchmark. However, it is always prudent business practice to evaluate if data collection costs will exceed projected benefits.

2.2.5 The Benchmarking Process

With the knowledge or what a benchmark, it is important to now distinguish the process of benchmarking from the benchmark. Recall that a benchmark represents an operating statistic, or metric, that serves only as a reference point for comparison. Therefore, a benchmark alone lacks the ability to interpret deviations, like the performance differences between industry counterparts (Bogan & English, 1994). In contrast to the benchmark, the *process* of benchmarking is a management tool that seeks to identify and understand the best industry standards among groups with a similar purpose (Figure 4).

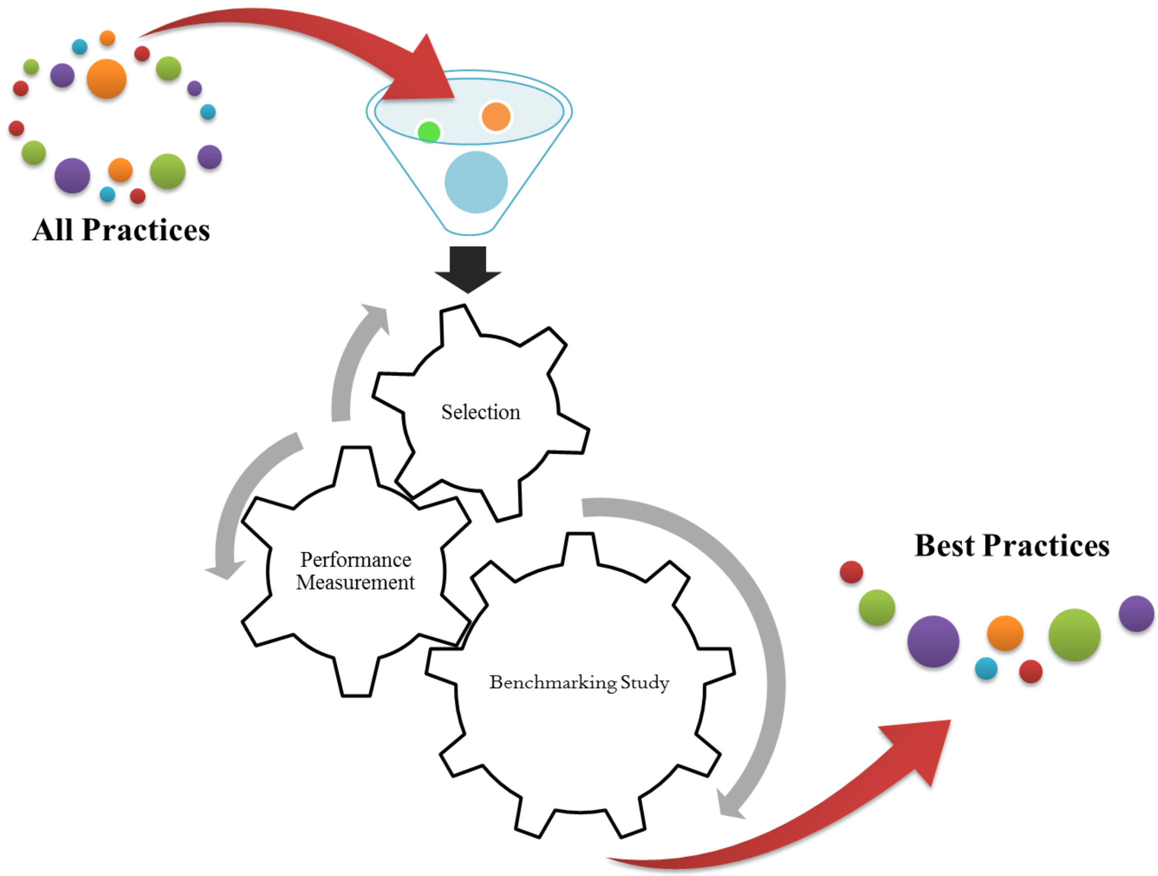


Figure 4: Summary of the benchmarking process

Bogan et al. stress that it is the benchmarking *process* that provides this necessary link between the act of benchmarking and the benchmark. As expressed by Bogan, successful best practice strategies are the result of the melding of both benchmarks and benchmarking. Consequently, it is imperative that the process of benchmarking and the benchmark be coupled to achieve optimal success. An accurate description of benchmarking comes from Robert Camp, “benchmarking is the search for industry best practices that lead to superior performance” (Camp, 1989). The emphasis being on the ‘search’ of proven performance measures as opposed to the arbitrary guessing of what may work.

2.2.6 Summary of Benchmarking

So how does a SHA rise to the top? A SHA, or any business, cannot expect to excel above its competition by merely employing arbitrary target-setting exercises based on internal historical experience (Camp, 1989). Thus the mindset of ‘this worked in the past’ must be avoided. So to, a business entity cannot just measure its performance against itself. Rather, a successful business must take a forward looking, comparative approach to the practices of its competition. This comparative ideology of best practices is the core concept behind the process of benchmarking.

There may be some misconceptions of what benchmarking is and is not. Benchmarking is not just an arbitrary picking of practices commonly used in the industry. On the contrary, benchmarking requires thoughtful selection of practices based upon a deep understanding of those practices; in other words, benchmarking metrics are never meant to be “quantified first and understood later” (Camp, 1989). Benchmarking must also be structured so that it can be implemented consistently across a specific business function. However, benchmarking must also remain flexible to allow incorporation of new, innovative ideas (Camp, 1989). Additionally, there is no definitive rule as to which benchmarking metrics should and shouldn’t be selected; each business will have a unique collection of benchmarking metrics. Ultimately, the benchmarking process is a *learning* experience supported by the selection of realistic performance goals (Camp, 1989).

Additionally, benchmarking is not a static program. Just as the business sector is a dynamic environment, benchmarking requires a continuous improvement management philosophy. Recall also that one of Behn's eight reasons for performance measurement was 'improve.' Another continuous improvement model that is particularly useful and simple to understand is Dr. W. Edwards Deming's 'Plan-Do-Check-Act' or PDCA cycle (Figure 5).

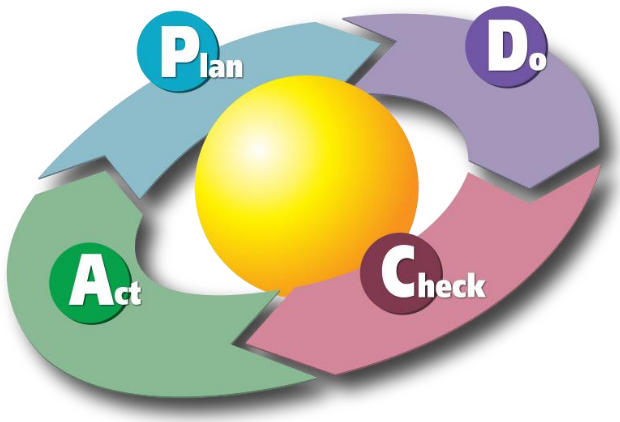


Figure 5: Plan-Do-Check-Act cycle (Bulsuk, 2009)

The PDCA cycle is based upon the scientific method of "hypothesis", "experiment", and "evaluation" and is a useful tool for driving continuous improvement and problem resolution. Other continuous improvement models are the Six Sigma and Kaizen programs. In the end, it does not matter which continuous improvement program is selected, so long as some system for continuous improvement of benchmarking and benchmarking metrics is implemented.

2.3 ARRA & MEGA PROJECTS

2.3.1 Background

Signed into law on February 17, 2009, the American Recovery and Reinvestment Act (ARRA) earmarked $27 billion for the Federal Highway Administration (FHWA) to distribute among the states for road, highway, and bridge projects for 2009 and 2010. However, the promise of federal aid was contingent to additional requirements, two of which being accountability and transparency. Before a roadway construction project could secure ARRA funds it had to prove its worth as a benefit to the public infrastructure. Additionally, SHA projects partially or wholly funded by ARRA dollars were required to maintain and publish timely monthly reports to the public, thus ensuring transparency and accountability.

Many of the requirements of the ARRA program were based on proven management best practices that the FHWA was already implementing on “Mega-projects.” A mega project is defined by the FHWA as a project that 1) cost over $500 million or 2) has a heightened level of public and political scrutiny due to the project’s significant costs (FHWA). Thus a mega project is not only synonymous with large budgets, it also can refer to the skill level required to manage such a complex project.

The Wisconsin DOT (WisDOT) has received $4.1 Billion in total ARRA funding to date (Figure 6); $710 Million of that total went specifically toward transportation projects (Recovery Accountability and Transparency Board, 2011). The WisDOT tracked each of these ARRA projects and submitted monthly reports on dollars expended and jobs created to the federal government, as required. In addition to these two metrics the WisDOT also tracked an extensive list of performance measures for internal use. Two of these metrics were ‘percent complete by time’ and ‘percent complete by cost’ and will be discussed in greater detail in Chapter 4.

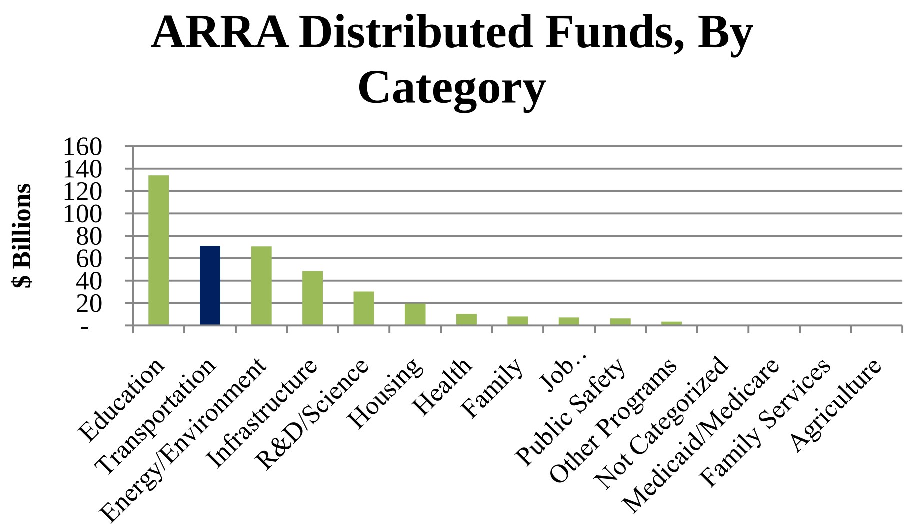


Figure 6: ARRA distributions for Wisconsin, adapted from (Recovery.gov, 2011)

Several interviews with WisDOT managers in charge of the state’s ARRA programs were conducted in late 2010 and early 2011. The consensus from those interviews was that all of the ARRA projects were deemed to be successful in regards to having favorable schedule and budget performance. What caused the WisDOT ARRA projects to be successful? Was it a direct result of the additional scrutiny, best practices, or tracking of performance measures? Was it a combination of all three? Undoubtedly something favorable resulted with these projects; Chapters 3 and 4 will take a deeper look into the likely causes of success on ARRA construction projects.

2.4 EARNED VALUE ANALYSIS

2.4.1 Introduction to Earned Value Analysis

Earned value analysis (EVA), also called earned value management, is a performance measure that objectively measures project scope, schedule, and cost. EVA holds an advantage over traditional project forecasting measures because EVA uses *current* project data to make its predictions rather than planned data. Moreover, since EVA is based on current data, it is a better vehicle for detecting slippage in both budget and schedule. For this reason, EVA is often referring to as an early-warning system because it allows the project management team to take corrective action early and mitigate risk. Additionally, both owner and contractor have a mutual interest in ensuring the construction project proceeds smoothly and without costly claims litigation.

The next several sections will take a deeper look into the specific advantages of EVA as a project management tool. Additionally, the requirements and challenges of implementing a successful EVA program will be addressed. Finally, an example of using EVA in construction will be examined.

2.4.1 Advantages of EVA

The true status of any project cannot be determined by just comparing planned vs. actual expenditures. Consider for example, a project manager that sees expenditures on a project 20% lower than expected. Is this good or bad news? Is better than expected productivity on the project resulting in higher efficiency and cost savings? Or is the project grossly behind schedule? These questions cannot be answered by the traditional methods of comparing planned vs. actual expenditures because "schedule and cost are linked in ways that enable them to mask each other's problems" (Cesarone, 2007). Conversely, EVA does provide an answer to the questions of budget and schedule. EVA allows the project management team to objectively quantify schedule and budget status, and it does so independently of one another (Cesarone, 2007). EVA can also be used to approximate value based on predicted costs.

The information provided by EVA can be used to mitigate risks to schedule and budget early in the project stage, where the ability to control costs is the greatest. Additionally, EVA can also be a powerful motivator to the project team, as people will generally work harder to correct poor performance if it is being consistently tracked and displayed (Cesarone, 2007); recall that 'motivation' was one of Behn's eight purposes of performance measurement.

2.4.2 EVA Requirements and Challenges

The enhanced explanatory power of EVA does not come without preconditions. First, EVA requires a well-planned project consisting of a minimum of three items: a task list, start and end dates for tasks, and anticipated labor hours for each task (Cesarone, 2007). These three items can typically be achieved by the 'baseline plan', which is a collection of a work breakdown structure (WBS), the schedule, the budget, and the resource plan (Kim & Reinschmidt, 2010). However, receiving good initial estimates for labor tasks on a project can be difficult without having access to historical productivity rates. Additionally, achieving all of the requirements for the baseline plan on small scope, small budget projects may not be feasible. This will be further discussed in Chapter 3. Second, EVA requires that both cost and percent complete data be regularly collected throughout the project duration. While cost data can usually be gleaned from accounting records, percent complete data can be determined using either of two primary means, weekly meetings or by counting deliverables (Cesarone, 2007). However, comparing money spent on a task to money allocated is an improper means of determining percent completion on a project (Cesarone, 2007).

There are additional challenges to achieving the requirements of EVA. Collecting data on progress achieved can be troublesome given the push-back often received from project supervisors. The reservations from these project supervisors may stem from the concern that the productivity numbers provided could potentially reflect negatively back on themselves (Cesarone, 2007). Furthermore, actual cost data can be difficult to collect in a timely manner if there is a lag period in transferring the data from accounting to the project management team. In addition to regular cost data, commitments to subcontractors or expensive equipment purchases need to be worked into the cost data at the time they are incurred, not later in the project when the invoices are received by accounting.

2.4.3 EVA in the field

While EVA has great power in providing numeric solutions, it can also be represented graphically to provide a quick overview of the project or task. The cumulative progress curve, or S-curve because of its sigmoid shape, is a common method used to convey progress at the task and project level (Figure 7) (Kim & Reinschmidt, 2010).

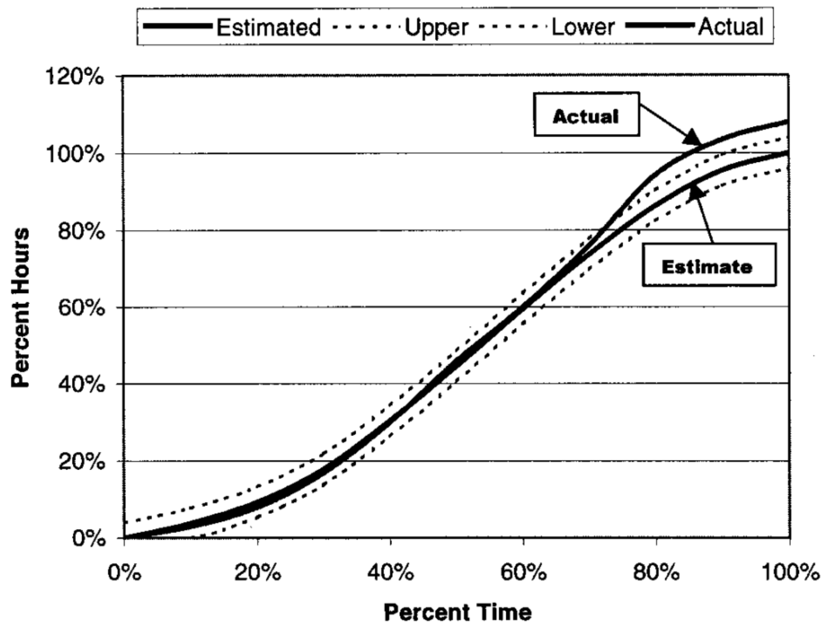


Figure 7: S-Curve example (Hanna, Peterson, & Lee, 2002)

The shape of the S-curve has a direct correlation to productivity rates. At the beginning of the project, the crews are mobilizing to the site and thus productivity, and earned value is low. This is shown by low slope on the EVA graph above. However, as mobilization nears completion and the learning curve is achieved, the crews begin to rapidly increase productivity; this is evident by the exponential increase on the EVA graph. Productivity continues to increase until the work crews reach a point of maximum productivity on the job. Productivity will typically remain at high until the project nears completion, at which point the productivity wanes as the crews finish up the bulk of their work and are left with rework and punch-list items.

Researchers in construction productivity have studied the characteristics of S-curves for many different construction trades. One example is the work performed by Dr. Awad

Hanna with electrical and mechanical contractors. Given the high labor risk with electrical and mechanical trades, Hanna investigated how S-curves can be useful resources for planning and tracking progress on construction projects (Hanna, Peterson, & Lee, 2002). Schedule and budget data were collected from contractors for 28 mechanical and 31 electrical projects and were then used to develop a series of S-curve control points (Hanna et al., 2002). These control points serve as future benchmarks for both contractors *and* owners to determine if their project is more-or-less on schedule and on budget (Hanna et al., 2002).

2.5 CONCLUSION

It has been shown that performance measures, benchmarks, and the overall benchmarking process drives continuous improvement among business entities, including SHAs. Many of these benchmarks have been included on Mega type projects for years, but more recently were federally mandated to be applied to ARRA projects. This presented an opportunity for the CMSC team to assess the benefit of one best practice in particular, employing S-curves and EVA. This is quite monumental, because while EVA has experienced growing use in vertical construction, its use in highway construction is not well documented. In fact, there is a complete lack of literature pertaining to the application of EVA and S-curves to transportation construction projects. Why is this? Given the apparent historic poor track record in terms of on time and on budget project delivery for transportation infrastructure projects in the US, and the multi-billion dollar SHA annual budgets, a tool such as EVA may offer a significant advancement in reducing project cost overruns. Answers to these questions will be addresses in great detail in chapter 3 and chapter 4.

CHAPTER 3

BEST PRACTICES WORKSHOP

3.1 INTRODUCTION

Chapter 2 detailed the advantages of using performance measurements and benchmarking to develop best practices. This chapter will now take a deeper, more focused view, of best practices in the context of SHA construction projects.

The WisDOT has been implementing best practices (BPs) on Mega and ARRA projects since 2004 and 2009 respectively. However, a comprehensive evaluation of the effectiveness of Mega and ARRA BPs had yet to be performed by the WisDOT. Therefore, it became the task of the Construction Material Support Center (CMSC) at the University of Wisconsin-Madison to identify a list of potential BPs and then evaluate that list to determine which BPs show the greatest potential for cost and time savings. The purpose of the study is to aid the WisDOT in determining which BPs should be implemented as department standard practice.

3.2 METHODOLOGY

To achieve the WisDOT study goals, the CMSC researched and developed an initial list of 45 best practices (BPs) focusing on four construction areas: 1) Project Management with Benchmarking and Metrics (PM), 2) Project Change Management (CM), 3) Document Control and Reporting (DC), and 4) Financial Reporting (FR). Many of the 45 best practices identified were based upon the Wisconsin Construction and Material Manual (CMM, 2010), the Construction Management Plan (CMP) for both the Marquette Interchange (completed

2008) and I-94 North-South Corridor (currently under construction) mega projects, the CMSC's direct experience working with WisDOT's construction program, and also through detailed interviews of senior WisDOT and state contractor personnel. As part of the identification process, each BP was given a concise description, along with visual aids when necessary (Figure 33, APPENDIX B.1)

The next step was to identify those BPs that produce the most benefit to WisDOT. Furthermore, two separate lists of BPs were created to account for the two main focus construction projects within the WisDOT, 3R/ARRA projects and Mega projects (Chapter 2); a third 'general' list would also be created to act as a catch-all category. '3R' stands for 'Resurfacing, Restoration, and Rehabilitation' and are the typical small scale projects that ARRA dollars funded.

The CMSC was unable to obtain any substantial historical performance measurement data from WisDOT regarding the cost and savings of individual BPs. A main reason for this lack of data is that WisDOT simply does not have a formal system of metrics tracking for their best practices. As an alternative to qualitative data, the CMSC organized a face-to-face best practices workshop that was attended by upper-level management from the WisDOT along with FHWA personnel and consulting engineers experienced in WisDOT project delivery practices. Representatives of the construction industry were interviewed later to gain their input. The workshop also had the added benefit of facilitating cross-department education among the participants, similar to the SCAN program used by the National Cooperative Highway Research Program (NCHRP, 2011). The open discussion questions during the survey allowed a productive means of inter-department and owner-consultant communication.

3.2.1 Data Collection

In February 2011, 24 professionals from WisDOT, FHWA and consulting engineering firms were selected to participate in an all-day workshop geared toward evaluating and ranking the list of 45 best practices that had been prepared by the CMSC. The BP workshop was structured to allow each participant an opportunity to rank each best practice based on a series of cost and value metrics developed by the CMSC. All participants in the workshop were notified that their responses would remain confidential with the intention of removing as many sources of respondent bias as possible.

Survey participants were asked a series of closed and open-ended questions for each BP. For the closed-ended questions, the participants were offered a choice of responses based on a modified psychometric Likert scale. A traditional Likert scale, often used in social science research, typically has five possible responses that the researcher can choose from. The responses can range from 1 being the most negative to 5 being the most positive (Table I).

Table I: An example of possible responses for a traditional Likert scale

1 =	Strongly Disagree
2 =	Disagree
3 =	Undecided
4 =	Agree
5 =	Strongly Agree

Alternatively, a four-response scale can be used which omits the neutral ‘Undecided’ option and thus forces the respondent to make a choice in either the negative or positive direction (Trochim, 2000).

The majority of the participants were WisDOT personnel and their particular areas of expertise were diverse. Therefore, it was unlikely that all members of the survey group had direct or indirect experience with the entire list of BPs. To overcome this issue, BP descriptions developed by the CMSC were provided to each participant to review prior to being asked a series of questions shown in Table II below.

Table II: Full list of survey questions and allowed responses

#	Question	Response Choices
I	To what degree do you feel you understand the application of this BP?	A. Not at all B. Somewhat C. Very Well
II	How experienced are you with using this BP?	A. Not at all B. Slightly C. Somewhat D. Very
III	Which best describes the description provided for the BP?	A. Not adequate and needs to be redone B. OK, but could be improved C. Not perfect, but acceptable D. Perfect, leave it alone
IV	Are there additional details that need to be added to add clarity or provide more information regarding the BP?	Open Ended Question
V	How effective do you think this BP is?	A. Not at all B. Slightly C. Somewhat D. Very E. Extremely

VI	How important do you think it is that this BP be implemented?	A. Not at all B. Slightly C. Somewhat D. Very E. Extremely
VII	When do you think the BP should be implemented on "Mega" type projects?	A. Not at all B. Only on a relatively few select projects C. On most, with a few exceptions D. On all as standard practice E. Don't know
VIII	When do you think the BP should be implemented on "3R" type projects?	A. Not at all B. Only on a relatively few select projects C. On most, with a few exceptions D. On all as standard practice E. Don't know
IX	How difficult will it be to implement this BP?	A. Not difficult at all B. A little difficult C. Somewhat difficult D. Very difficult E. Don't know
X	Are there any additional cautions that should be kept in mind when trying to implement this BP?	Open Ended Question
XI	This BP will result in the following cost impact to the Department/Region if implemented?	A. Have no impact on costs B. Slightly increase costs C. Moderately increase costs D. Significantly increase costs E. Not sure
XII	Implementation of this BP will require the following:	A. Nothing B. Additional manpower C. New or modified software D. Hardware or equipment E. Technical training F. New standard/special provisions
XIII	Are there example projects where this BP has been used?	Open Ended Question

Some of the questions from Table II above, such as III and IV, were included as a means of internal feedback on how the CMSC could improve upon its BP descriptions. These internal-use questions, along with the open-ended questions X, XIII and also question XII, were moved into a separate database for later review. The remaining nine questions (Table III) were analyzed using a series of statistical algorithms to determine which BPs ranked among the top in terms of potential for cost and schedule savings.

Table III: Nine closed-ended questions asked for each best practice

#	Question
1	To what degree do you feel you understand the application of this BP?
2	How experienced are you with using this BP?
3	Which best describes the description provided for the BP?
4	How effective do you think this BP is?
5	How important do you think it is that this BP be implemented?
6	When do you think the BP should be implemented on "Mega" type projects?
7	When do you think the BP should be implemented on "3R" type projects?
8	How difficult will it be to implement this BP?
9	This BP will result in the following cost impact to the Department/Region if implemented?

The closed-ended responses were collected and stored electronically using iClicker® technology. Each member of the survey group was assigned a specific iClicker® device, allowing the CMSC to track individual responses and to detect any correlations between response and level of seniority or department. In addition to the iClicker® technology, time constraints required that a portion of the survey be completed via the online Qualtrics© survey software program. The online survey mirrored the in-person survey, including the ability to track individual responses and comments.

Electronic polling was chosen for its numerous benefits. First, electronic polling allowed for more rapid and accurate data collection by removing human processing time and error. Furthermore, the software package also allowed for the after-the-fact, anonymous display of survey results for select questions (Figure 8). Specific questions that the CMSC thought would be beneficial to the survey group had their results displayed. Additionally, requests by the participants to see the question results were generally honored. However, in the interest of time, and also not to induce respondent bias, not all requests were permitted.

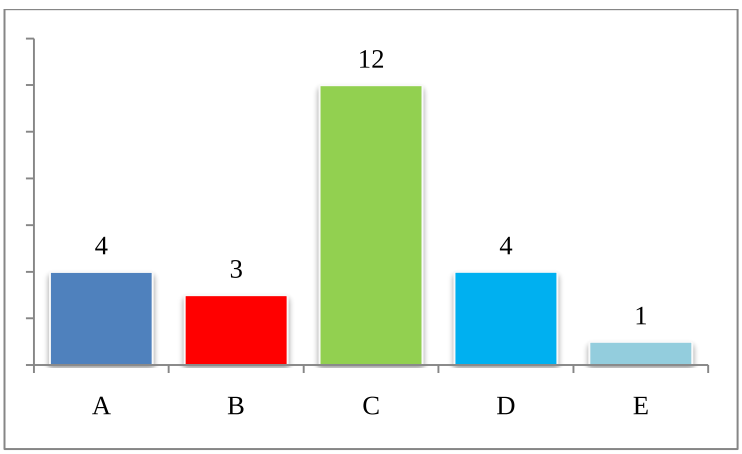


Figure 8: Example results bar-chart displayed during survey workshop

3.3 RESULTS

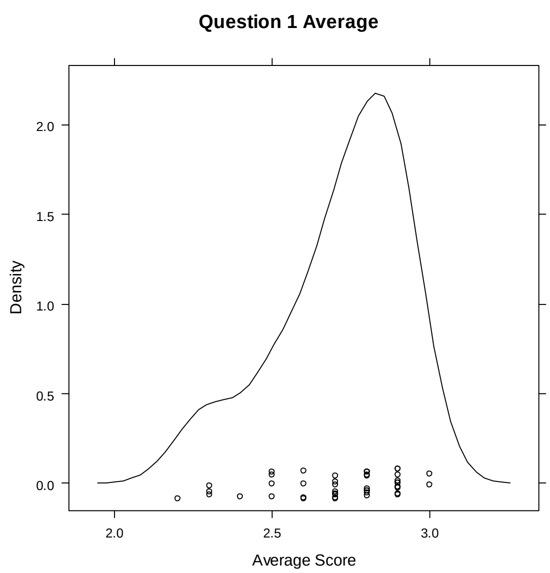
Results from both the in-person workshop and online survey were collected and consolidated into a single spreadsheet. Next, a scoring system was invoked to apply equal weight to each question. The weighting system was intended to be arbitrary, and to only serve as a means of converting the alpha-formatted categorical variable into more manageable numeric format. The scoring system sequentially assigned an integer value starting with "1" for response A, "2" for response B, and so on (See Table IV below). However, not all of the questions had the same number of possible responses. For example, Question I related how well the respondent understood the application of the BP and allowed three response options 1) Not at All, 2) Somewhat and 3) Very Well. In contrast, the rest of the questions had four or five response options. Therefore, not all questions would have the same scoring scale length; certain question types would be 1-2-3 while others may be 1-2-3-4. This was not a critical issue, but would impact how the data could be analyzed later.

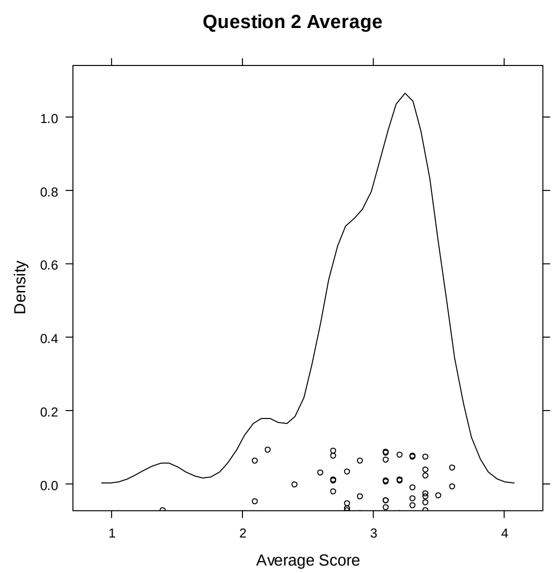
Next, an initial score was calculated for each of the nine questions and then repeated for each of the 45 BPs, 405 averaged scores in total. An example calculation for best practice FR-1 is shown below in Table IV; a complete list of the averaged scores is shown in Table XVI of APPENDIX B.2.

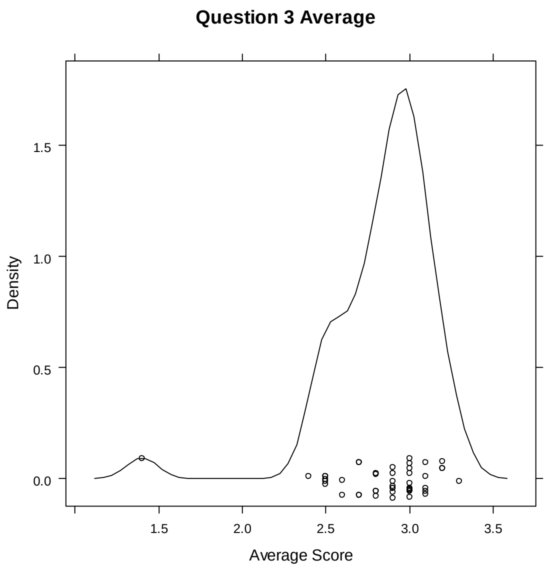
Table IV: Example calculation for BP average score

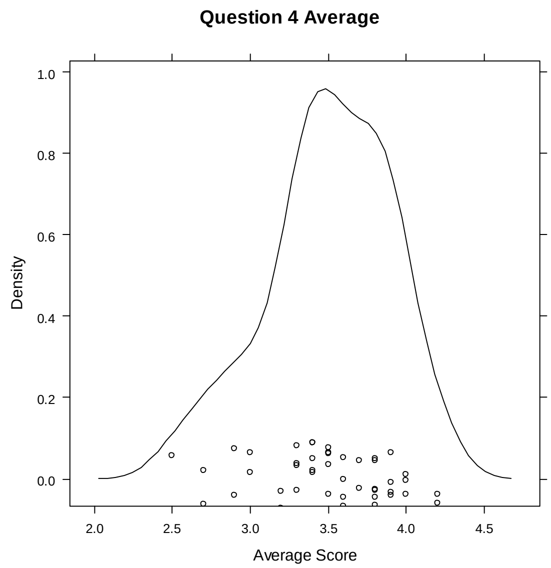
Response	Response Count	Scoring Scale	Score
A	5	1	5
B	9	2	18
C	10	3	30
Total	24	--	53
Average Score = (Total Score) / (Total # of Responses) **= 2.21**			

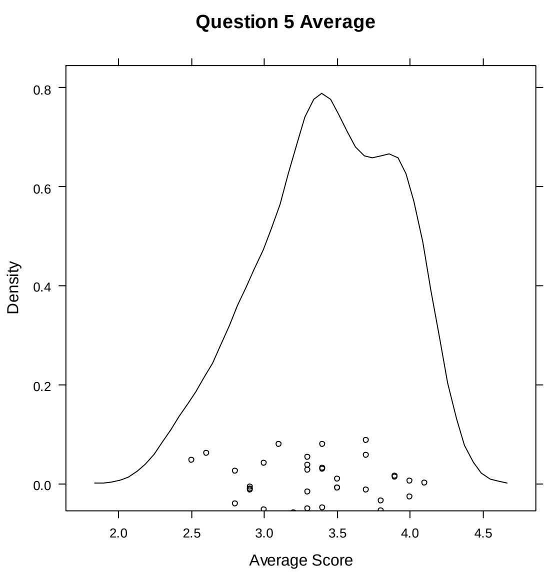
While the survey data is technically discrete and should be displayed as a bar chart, there are so many possibilities for average score that it really does not matter much if the data is treated as if it were continuous, thereby allowing the data to be plotted as histogram. Thus the 45 responses for each of the nine questions, one for each BP, were tabulated and displayed graphically using a kernel-density plot. The nine kernel-density plots were created using the statistics package R and are the result of generating many histograms of differing bin width and then plotting a curve through the average bin height. Presenting the data in a density plot obviates the requirement of having to select a bin size, which saves the data from the possibility of being misrepresented by subjective bin sizes that are too small or too large. The results of the density plots for each of the nine question types are shown below (Figure 9).

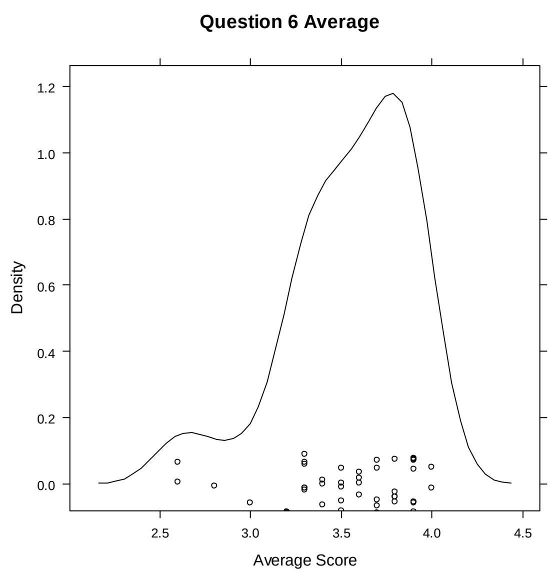





Question 3 Average
Density
Average Score


Question 4 Average
Density
Average Score


Question 5 Average
Density
Average Score


Question 6 Average
Density
Average Score

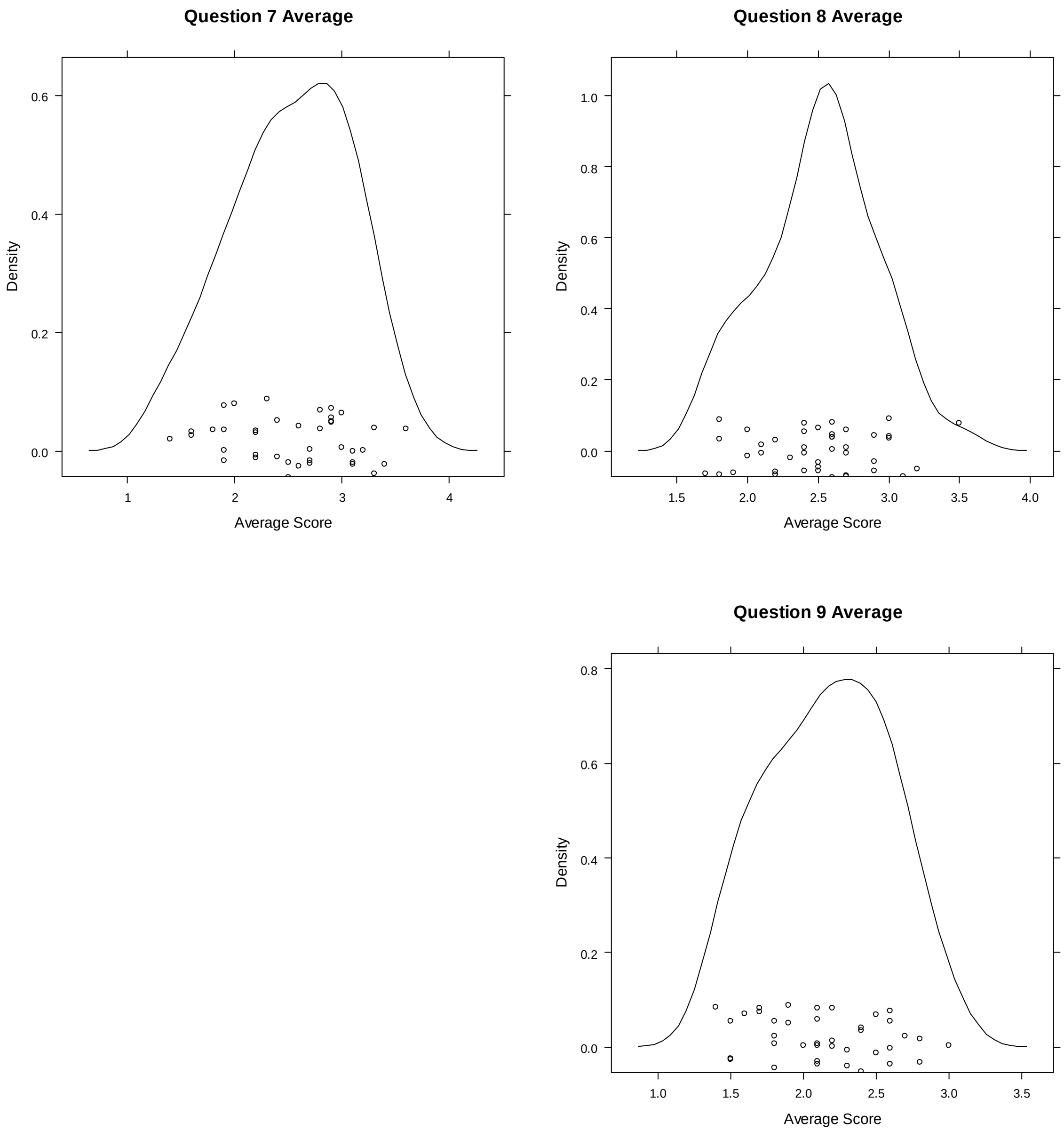


Figure 9: Kernel density plots of the averaged BP scores

Each point on the density plot represents one of the 45 BPs. The points were 'jittered' vertically merely to avoid points overlapping one another; the vertical deviation of the individual points is therefore without meaning; only the curved line represents the outcome of the histogram shifts. The density plots resemble the shape of a standard normal distribution plot, which are also based on continuous variables. However, unlike the standard normal distribution, the average-score density plots are not centered about zero (Figure 10). Additionally, the data plots clearly show the varying widths of the density distributions, indicating that certain questions had more variance or greater disagreement among the survey group.

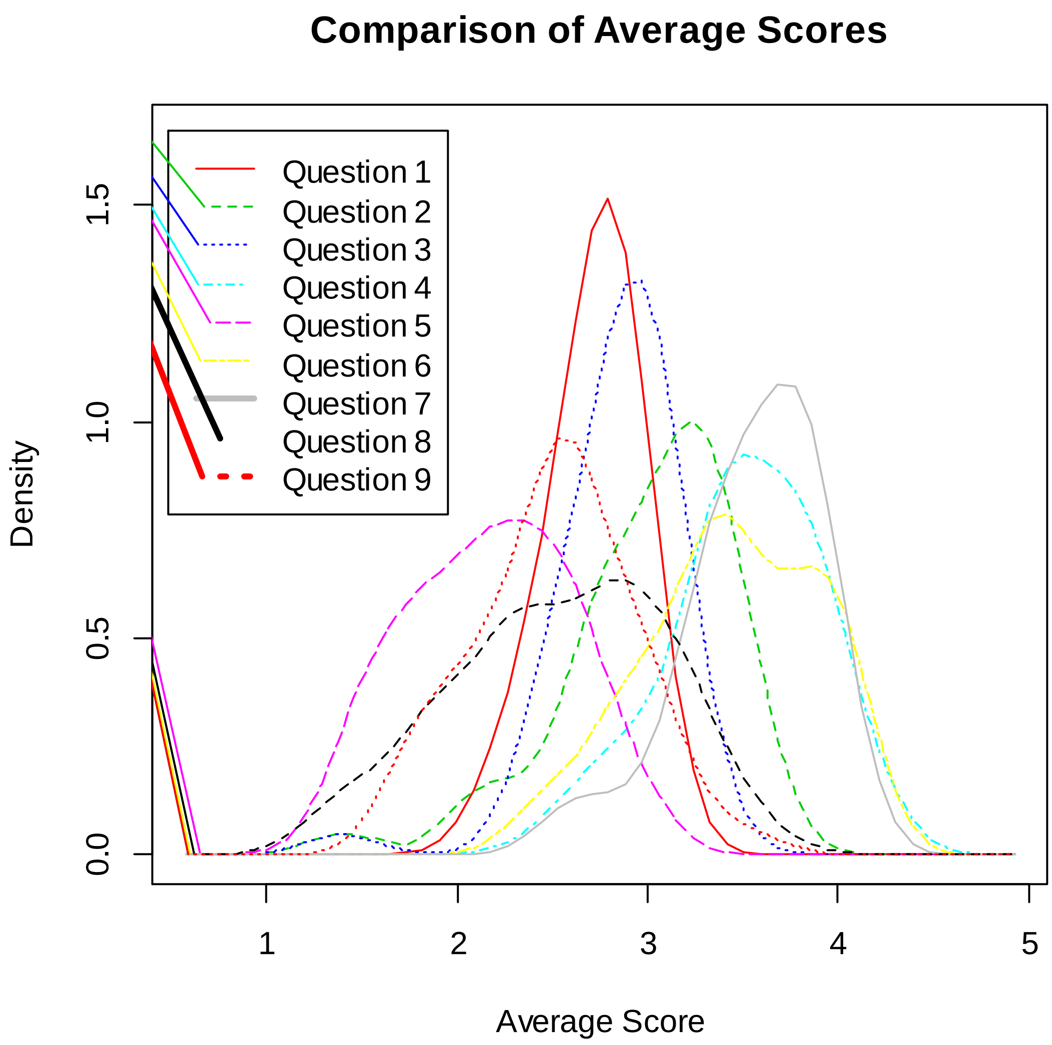


Figure 10: Comparison of all nine average score density plots

While averages and standard deviations are useful tools, they do not easily allow comparison between two populations. This is especially true given that the closed-ended BP survey responses were not on the same scale. A better method for data comparison is the standard normal deviate or z-score. Use of the z-score is a more powerful tool over simple averages because it provides both a means of ranking each BP against its competitors on a normalized scale as well as displaying the spread of the data. Furthermore, with a standard normal scale the responses from Questions 1 through 9 could be combined without any ill-effects resulting from the questions having different original responses scales.

Additionally, since the z-score is based on a standard normal distribution, the change in z-scores among BPs has statistical significance. With averages based on categorical data, a change of say 1.67 does not have a true meaning, as two people could interpret the change differently. In contrast, z-scores allow the reader a real scale on which to base a comparison. For example, fundamental statistics indicates that roughly 68% of the data lies within ± one standard deviation of the mean, which is zero for a normal distribution. Therefore, any BP z-scores falling outside of this 68% range, whether positive or negative, would warrant further investigation. Moreover, a BP with a negative composite z-score indicates that the BP ranked less than average and therefore may not be the ideal choice as a WisDOT department BP.

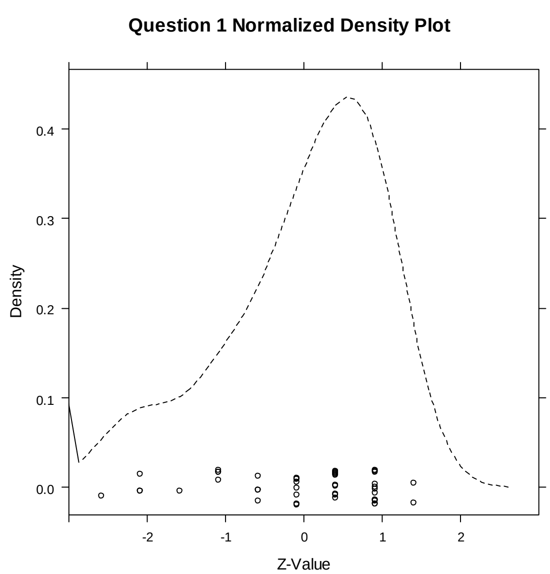
The z-score for each BP was calculated for each of the nine question types using the question’s mean and question’s standard deviation calculated earlier (Eq.1).

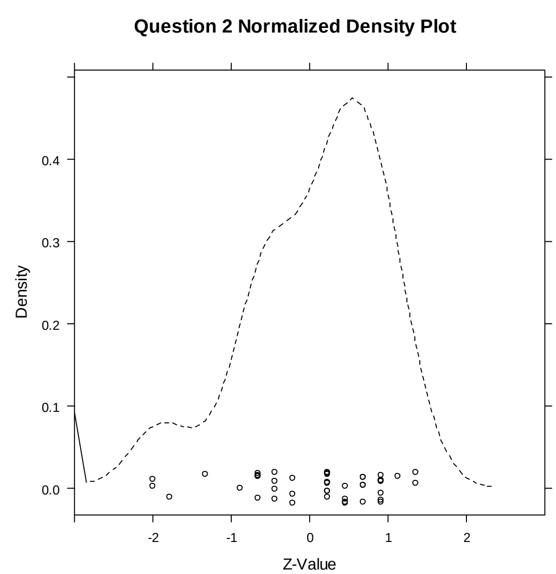
$$z\_score_{ij} = \frac{mean_{ij} - mean_j}{stdev_j}$$

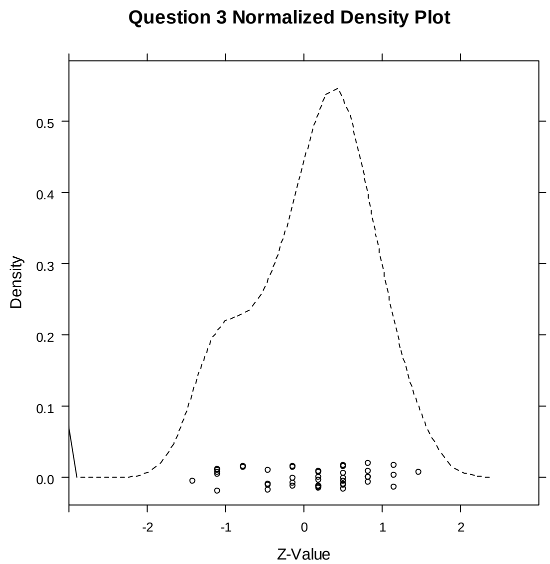
Eq.1: Z-Score formula, i^{th} observation of the j^{th} question type.

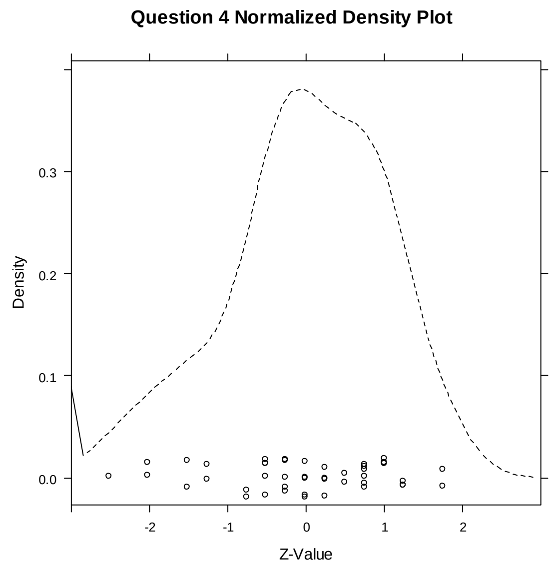
It should be noted that questions 8 and 9 originally had a scale that was in contrast with the other questions. All of the other questions had response "A" being the most negative; however, questions 8 and 9 initially had response "A" being the most positive in terms of applicability. Since z-scores were being used, the solution was simply to reverse the sign of the original z-score for questions 8and 9 only. The z-scores from the questions representing each scenario were then summed and sorted (Table XVII, APPENDIX B.3)

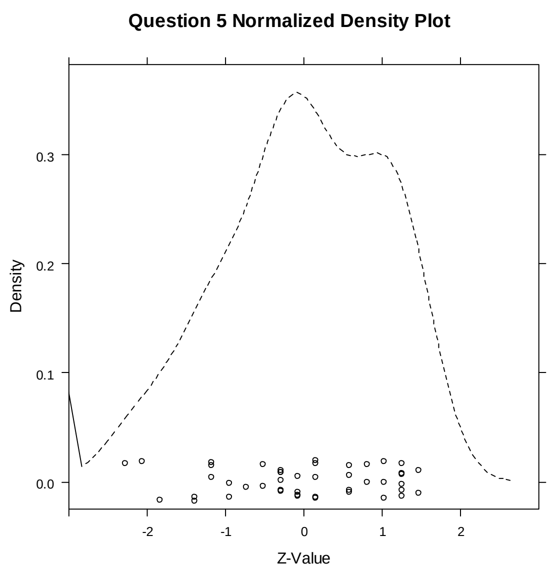
The z-core data can also be displayed graphically with a kernel-density plot (Figure 11), the same format as average scores. Note how the z-score plots are now all centered near 0, in contrast to the average score plots that varied in the location of their mean point.

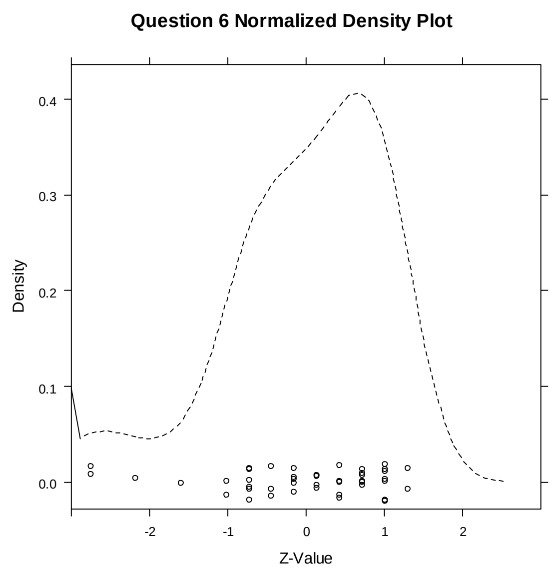





Question 3 Normalized Density Plot
Density
Z-Value
0.0
0.1
0.2
0.3
0.4
0.5
-2
-1
0
1
2


Question 4 Normalized Density Plot
Density
Z-Value
0.0
0.1
0.2
0.3
-2
-1
0
1
2


Question 5 Normalized Density Plot
Density
Z-Value
0.0
0.1
0.2
0.3
-2
-1
0
1
2


Question 6 Normalized Density Plot
Density
Z-Value
0.0
0.1
0.2
0.3
0.4
-2
-1
0
1
2

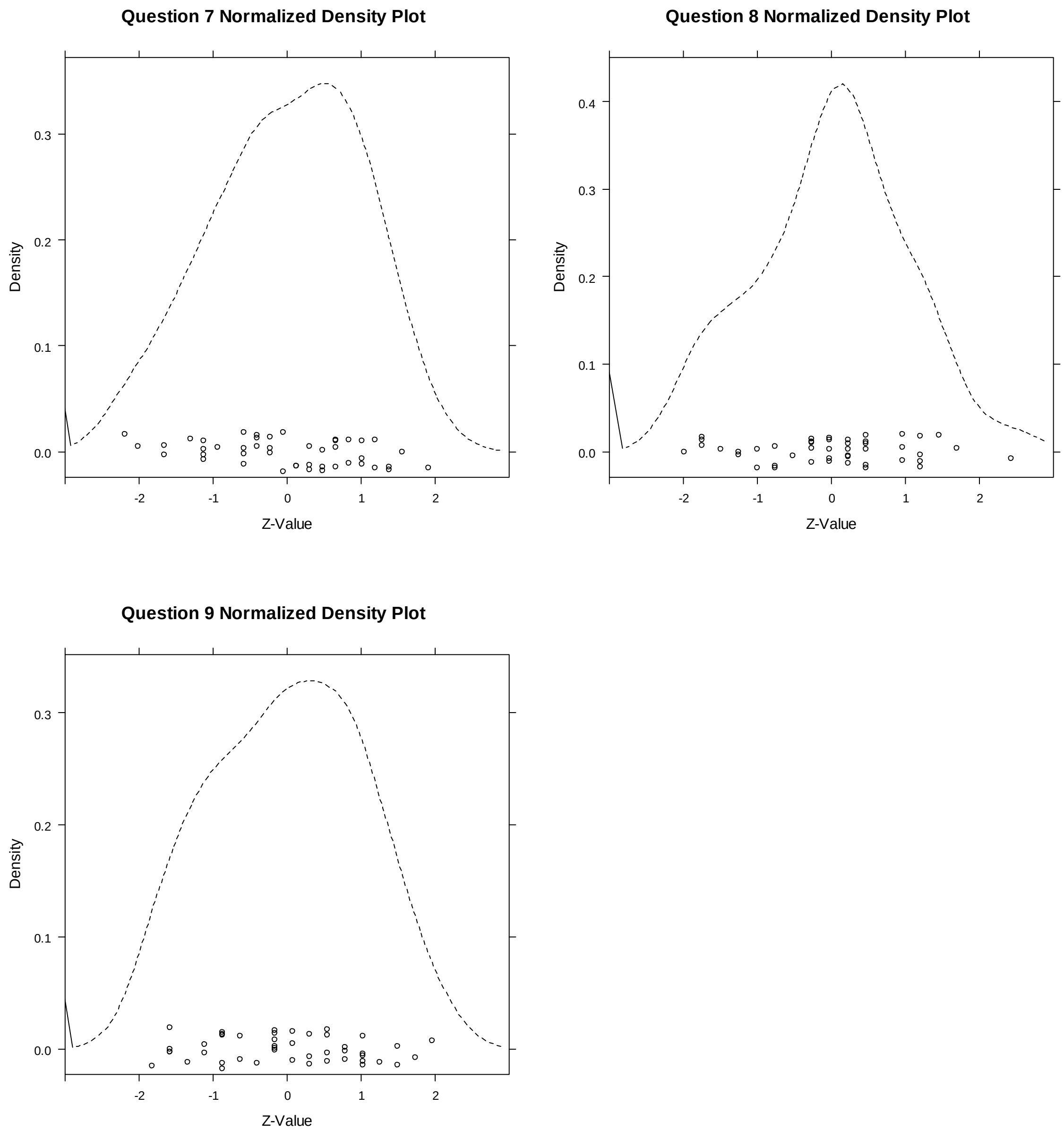


Figure 11: Kernel density plots for BP z-score

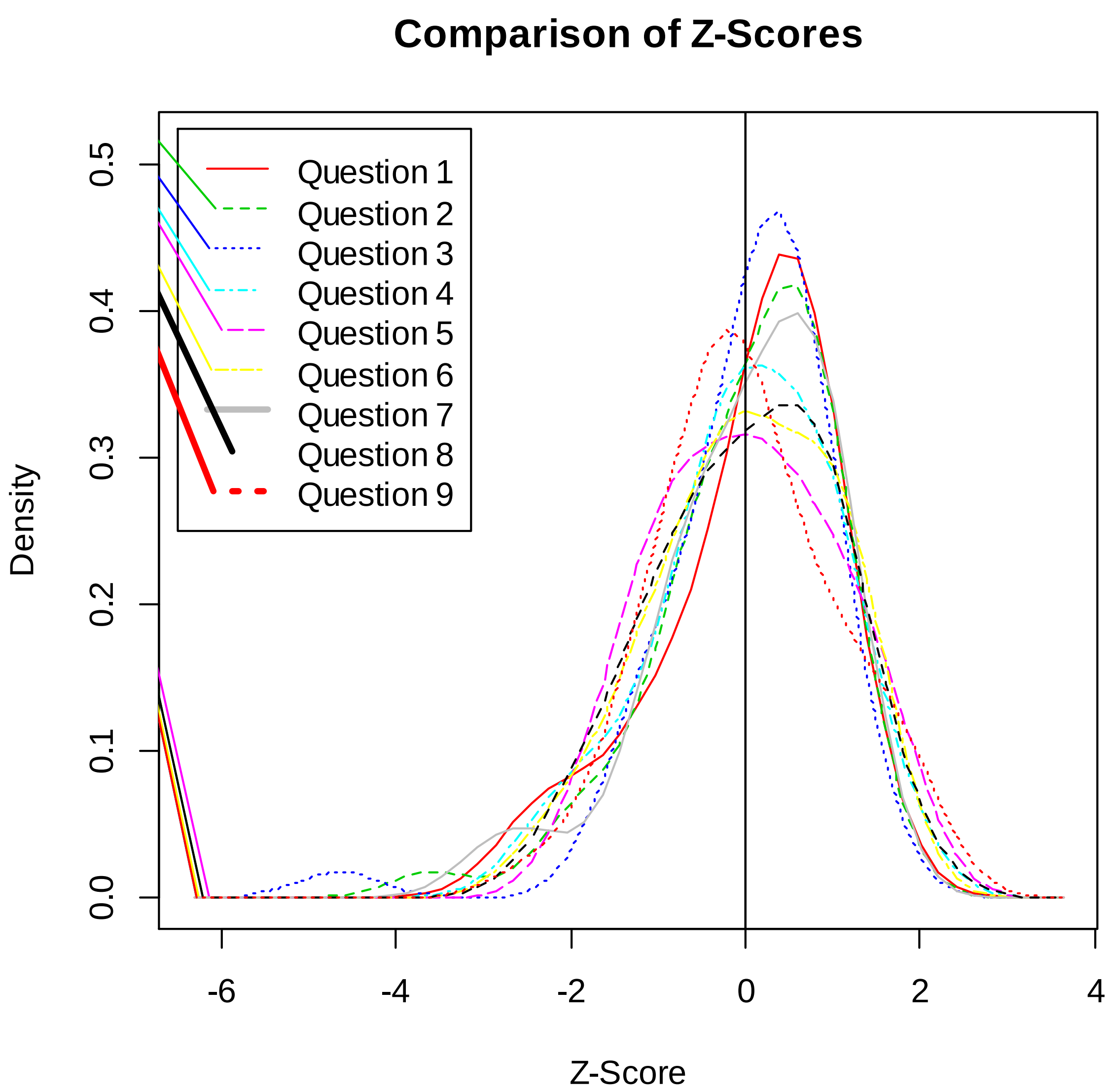


Figure 12: Comparison of the z-score distribution

With z-scores for all the BPs, the final step was to rank and sort those BPs that showed the greatest potential toward cost and schedule savings on roadway construction projects. This ranking process required first combining relevant question types. For this research, all construction projects fall into three categories: Mega projects, 3R/ARRA projects, and general projects. Three categories, A, B, and C, were thus created that represented the three logical applications for ranking the list of 45 BPs. Category "A" represents the case of a general construction project. Additionally, category "A" is broad reaching and would cover those construction projects whose scope does not fit well into either Mega or 3R type projects. Finally, category A is based on survey responses to questions 4, 5, 8, and 9. Conversely, categories "B" and "C" are more specific than "A" and represent construction projects categorized as Mega and 3R respectively. Therefore, category "B" was based on questions 6, 8, & 9 while category "C" incorporated questions 7, 8, & 9 (Figure 13).

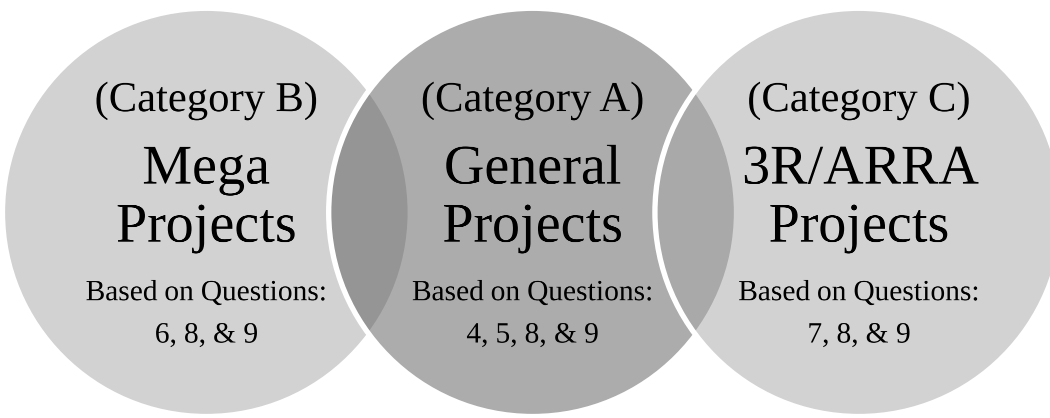


Figure 13: Three categories for ranking the 45 BPs

The z-scores within these three categories were sorted by rank and are displayed below (Table V).

Table V: Z-score rankings of all 45 BP across the three categories

Rank	Scenario A [General]		Scenario B [Mega]		Scenario C [3R/ARRA]	
1	PM-16	6.9	PM-16	4.5	PM-16	5.0
2	PM-21	5.5	PM-21	4.3	PM-21	4.9
3	PM-1	5.4	PM-1	4.3	PM-9	4.4
4	PM-9	4.5	PM-17	3.7	PM-1	4.4
5	PM-17	4.4	PM-9	3.6	PM-17	3.3
6	PM-6	3.8	PM-6	3.5	PM-6	3.2
7	PM-20	3.7	PM-28	2.6	PM-29	2.9
8	CM-4	3.5	PM-29	2.6	PM-28	2.5
9	PM-2	3.1	PM-2	2.5	PM-20	2.5
10	PM-28	3.0	PM-20	2.5	PM-2	2.1
11	PM-24	2.8	DC-2	2.0	DC-2	1.8
12	PM-14	2.3	CM-4	1.7	PM-14	1.7
13	PM-29	1.5	PM-14	1.6	CM-4	1.7
14	PM-11	1.4	PM-4	1.4	PM-12	1.4
15	PM-4	1.3	PM-24	1.1	PM-30	1.4
16	PM-12	1.0	CM-3	1.1	PM-24	1.3
17	FR-2	1.0	PM-19	0.9	CM-3	1.2
18	DC-2	0.8	PM-12	0.8	FR-2	1.1
19	PM-10	0.8	FR-2	0.3	PM-19	0.9
20	CM-3	0.5	PM-11	0.1	PM-4	0.7
21	FR-1	0.2	PM-8	0.1	PM-23	0.2
22	CM-1	-0.1	PM-23	0.0	PM-11	0.1
23	PM-25	-0.2	CM-1	-0.4	PM-27	-0.4
24	CM-5	-0.4	PM-30	-0.4	PM-26	-0.5
25	PM-8	-0.4	CM-7	-0.5	FR-1	-0.5
26	PM-5	-0.6	DC-6	-0.6	CM-5	-0.5
27	PM-23	-0.8	FR-1	-0.6	DC-5	-0.8
28	CM-7	-0.9	CM-5	-0.7	PM-8	-0.8
29	DC-5	-1.2	PM-26	-0.9	DC-6	-0.8
30	PM-19	-1.2	PM-5	-0.9	CM-1	-0.9
31	PM-15	-1.4	DC-5	-1.0	CM-7	-1.0
32	DC-6	-1.7	PM-27	-1.3	PM-5	-1.7
33	PM-27	-1.8	PM-15	-1.6	PM-7	-1.9
34	PM-30	-2.0	PM-3	-1.6	CM-2	-2.1
35	CM-2	-2.3	CM-2	-1.7	PM-3	-2.1

36	PM-3	-2.3	PM-22	-2.0	PM-15	-2.1
37	PM-22	-2.6	PM-7	-2.1	PM-18	-2.4
38	PM-7	-2.6	DC-1	-2.1	DC-1	-2.8
39	PM-26	-2.8	PM-10	-2.2	PM-22	-3.0
40	DC-3	-3.5	PM-25	-2.6	PM-25	-3.0
41	DC-1	-4.2	PM-18	-3.1	DC-4	-3.2
42	PM-31	-4.9	DC-3	-3.5	DC-3	-3.6
43	PM-18	-5.0	DC-4	-4.9	PM-10	-3.8
44	DC-4	-6.3	PM-13	-5.1	PM-31	-5.1
45	PM-13	-8.1	PM-31	-5.3	PM-13	-5.8

The table above shows that the cumulative z-score begins to quickly drop off near the tenth BP. This drop provided the research team with a good separation point between those BPs that would be recommended to a SHA and those that would not. It also conveniently allowed for a 'top-ten' list.

Focusing on just the top 10 BPs for each of the three categories of construction, the individual z-scores and their ranks were compared to the overall rank (Table VI). Note that the overall top 10 BPs are not necessarily composed of questions with top ten ranking. For example, PM-21 in category 'A' was ranked 2nd overall but was ranked 12th based on question 5.

Table VI: Top 10 BPs with individual and composite z-scores plus [rank]

	Category A [General]					
Composite Rank	BP	Q4 [rank]	Q5 [rank]	Q8 [rank]	Q9 [rank]	**Overall**
1	PM-16	1.7 [2]	1.6 [1]	1.9 [2]	1.8 [1]	6.9
2	PM-21	1.2 [5]	0.9 [12]	1.9 [3]	1.6 [4]	5.5
3	PM-1	1.0 [7]	1.2 [4]	1.5 [5]	1.6 [3]	5.4
4	PM-9	0.9 [9]	1.0 [9]	0.9 [9]	1.7 [2]	4.5
5	PM-17	0.7 [15]	0.5 [17]	2.0 [1]	1.2 [7]	4.4
6	PM-6	0.7 [12]	0.2 [20]	1.6 [4]	1.2 [8]	3.8
7	PM-20	0.9 [8]	0.7 [14]	1.2 [7]	0.9 [10]	3.7
8	CM-4	1.3 [3]	1.2 [3]	0.7 [11]	0.2 [18]	3.5
9	PM-2	0.8 [11]	0.8 [13]	1.2 [6]	0.3 [17]	3.1
10	PM-28	0.7 [13]	0.6 [16]	1.1 [8]	0.6 [15]	3.0

	Category B [Mega]				
Composite Rank	BP	Q6 [rank]	Q8 [rank]	Q9 [rank]	**Overall**
1	PM-16	0.9 [7]	1.9 [2]	1.8 [1]	4.5
2	PM-21	0.9 [8]	1.9 [3]	1.6 [4]	4.3
3	PM-1	1.2 [3]	1.5 [5]	1.6 [3]	4.3
4	PM-17	0.5 [17]	2.0 [1]	1.2 [7]	3.7
5	PM-9	1.0 [5]	0.9 [9]	1.7 [2]	3.6
6	PM-6	0.7 [14]	1.6 [4]	1.2 [8]	3.5
7	PM-28	0.9 [9]	1.1 [8]	0.6 [15]	2.6
8	PM-29	0.7 [13]	0.6 [13]	1.2 [6]	2.6
9	PM-2	1.0 [4]	1.2 [6]	0.3 [17]	2.5
10	PM-20	0.4 [21]	1.2 [7]	0.9 [10]	2.5

	Category C [3R/ARRA]				
Composite Rank	BP	Q7 [rank]	Q8 [rank]	Q9 [rank]	**Overall**
1	PM-16	1.4 [3]	1.9 [2]	1.8 [1]	5.0
2	PM-21	1.5 [2]	1.9 [3]	1.6 [4]	4.9
3	PM-9	1.9 [1]	0.9 [9]	1.7 [2]	4.4
4	PM-1	1.3 [4]	1.5 [5]	1.6 [3]	4.4

5	PM-17	0.1 [23]	2 [1]	1.2 [7]	3.3
6	PM-6	0.3 [21]	1.6 [4]	1.2 [8]	3.2
7	PM-29	1.1 [9]	0.6 [13]	1.2 [6]	2.9
8	PM-28	0.8 [11]	1.1 [8]	0.6 [15]	2.5
9	PM-20	0.4 [20]	1.2 [7]	0.9 [10]	2.5
10	PM-2	0.6 [16]	1.2 [6]	0.3 [17]	2.1

Also, upon closer inspection, the overall top 10 BPs across the three scenarios are very similar. In fact, nine of ten BPs are common among the general, Mega, and 3R categories; only CM-4 and PM-29 fall in and out of the top ten. Furthermore, the nine common BPs are all related to project management; only one change management BP (CM-4) was ranked among the top 10. These cumulative top 11 BPs will be referred to as the '9+2 BPs' from here on out.

Additionally, the top ten lists for the Mega and 3R categories have the same BPs identified, just ranked in a different order. Therefore, the results of the survey suggest that the BPs identified as being top performers among Mega projects, also apply to the smaller budget and shorter duration 3R/ARRA projects. From a general perspective, WisDOT could potentially see improved cost and schedule savings by implementing any of the 9+2 BPs.

3.4 SUMMARY

3.4.1 Comments on Methodology

First, it is very important to recall that the data responses obtained through the best practices workshop were categorical and ordinal—having a nature order or rank. Therefore, the data was not quantitative but qualitative. Applying the numeric coding system to the qualitative data did not convert the data to true quantitative form; the data was still based on categorical responses. However, the coding system did allow for the qualitative results to be displayed in a more meaningful and clear way across all 45 BPs.

Additionally, categorical data does not discount the data's worth, but it does come with some caveats on how the data should be analyzed. For example, the categorical data is technically discrete and therefore cannot possess a true standard normal distribution. While it was acceptable to plot the data as a histogram instead of a bar-chart it would not be appropriate to perform a t-test on the 'score' values to compare questions.

The modified Likert scale used for the best practices workshop created unique concerns and assumptions and could be improved upon in future studies. First, as was shown earlier in Table II, the response scale was not uniform for all questions. As it was, the survey participant may have become confused trying to decide what a response of "2" really meant to them, and whether the difference between a "1" and a "2" meant the same as the difference between a "4" and a "5". Also, it would be beneficial if all of the questions had the same choice of responses. It would be up to the researcher to decide whether to use a 4-choice or 5-choice Likert scale. Having a standard scale would ease the analysis and would likely also reduce respondent error. For example, the survey used in the workshop had switched the scales for questions 8 and 9. This switch may have inadvertently caused some of the participants to answer incorrectly. While all qualitative data involves a certain amount of assumptions and judgments about what each number means, the varying scales of the responses introduced addition confusion that should be corrected for in future studies.

However, the research team was able to use the standard normal deviate to remove some of this uncertainty over the scoring scale.

3.4.2 Comments on Results

There were nine BPs that consistently were in the top ten, even across each of the three different scenarios: Mega, 3R, and general (Table VII); see Appendix B.5 for full BP descriptions prepared by the CMSC. In addition, the two BPs PM-29 and CM-4 were in the top rankings but were dependent upon the construction project category. Furthermore, many of the BPs appearing on all three lists also appeared in a similar rank sequence. For example, PM-16 and PM-21 were ranked 1st and 2nd respectively across all three categories.

Table VII: Top nine BPs among all categories plus two category-dependent BPs

BP #	**BP Description* (Sorted Alphabetically)**
PM-1	Employ a defined hierarchy for decision making
PM-2	Use a Request for Information (RFI) form and process
PM-6	Require Use of Three-Week Look-Ahead Schedules
PM-9	Establish project Close-Out Procedures early in project and track progress
PM-16	Assign a responsible party for resolution of issues at Project Progress Meetings
PM-17	Make “Open Issues” a routine agenda item at Project Progress Meetings
PM-20	Hold Specialty Group Meetings
PM-21	Use Work Authorization Form (WAF)
PM-28	Encourage Third-Party representation at Project Progress Meetings
PM-29	Establish project goals for timely approval of documents
CM-4	Conduct Weekly Issues Meeting

* BP descriptions obtained from CMSC Best Practices Booklet.

As a final check on the data, the top BPs were cross-checked against the level of understanding and the level of experience of the survey participant, questions 1 and 2 respectively. This is important since the data collected from this survey would not be meaningful if the participants were not familiar with the BPs they were ranking. Table XVI (Appendix B.2) shows a mean of the averaged scores for questions 1 and 2 to be 2.7 and 3.0 respectively; recall also that questions 1 and 2 had a maximum allowable score of 3.0 and 4.0 respectively. Therefore, it is apparent that the survey audience had a favorable level of understanding for the entire list of BPs, but had a lesser degree of prior experience using the BPs. However, while all of the 9 + 2 BPs identified had desirable levels of experience, showing only half a standard deviation lower than the mean (Table VIII), the level of experience for the lowest ranked BPs was trending low (Table VIII).

Table VIII: Level of understanding and experience of participants for top 9 + 2 BPs

BP	Question 1	Question 2
⋮	⋮	⋮
PM-1	3.0 [1]	3.6 [1]
PM-17	2.9 [5]	3.6 [2]
PM-16	3.0 [2]	3.4 [4]
PM-28	2.8 [20]	3.4 [7]
PM-9	2.8 [18]	3.4 [10]
CM-4	2.9 [7]	3.3 [11]
PM-20	2.7 [28]	3.3 [13]
PM-2	2.9 [13]	3.2 [16]
PM-29	2.9 [8]	3.2 [19]
PM-6	2.8 [17]	2.9 [28]
PM-21	2.6 [33]	2.8 [31]
⋮	⋮	⋮
Question Mean (n=45)	2.7	3.0
Question SD (n=45)	0.19	0.44

*** [Rank] is shown along with the average-score**

The correlation coefficient, ρ, between level of understanding and composite Z-score for category A, was found to be 0.47 (Figure 14).

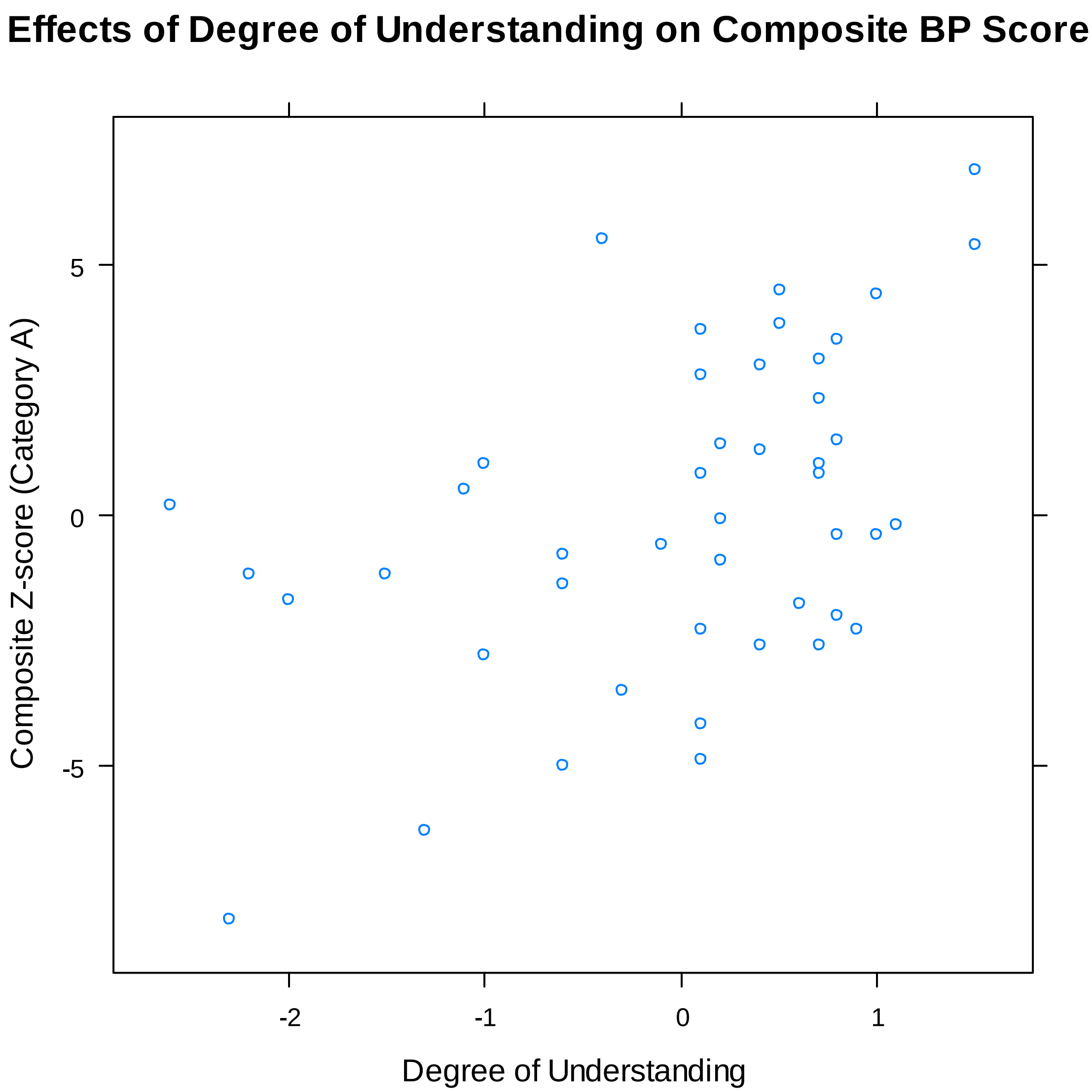


Figure 14: Correlation between degree of understanding and composite z-score

A student t-test was used to determine if there was a relationship between these two factors:

H_0: There is no relationship between the degree of understanding and the overall z-score of a BP ($\rho = 0$)

H_A: Degree of understanding and the overall z-score of a BP are correlated ($\rho \neq 0$)

The results of the student t-test are shown below:

n = 45 ; df = 43 ; SE_ρ= 0.1345 ; Test statistic, t = 3.50; **p-value = 0.0011<<0.05**

Since the p-value is less than 0.05, the null hypothesis is rejected in favor of the alternative. Therefore, there is strong evidence that the participant's level of understanding of the BP was correlated to the overall composite z-score.

Similarly, the correlation between level of experience and composite z-score can also be tested. The correlation coefficient, ρ, between level of experience and composite Z-score for category A, was found to be 0.52 (Figure 15).

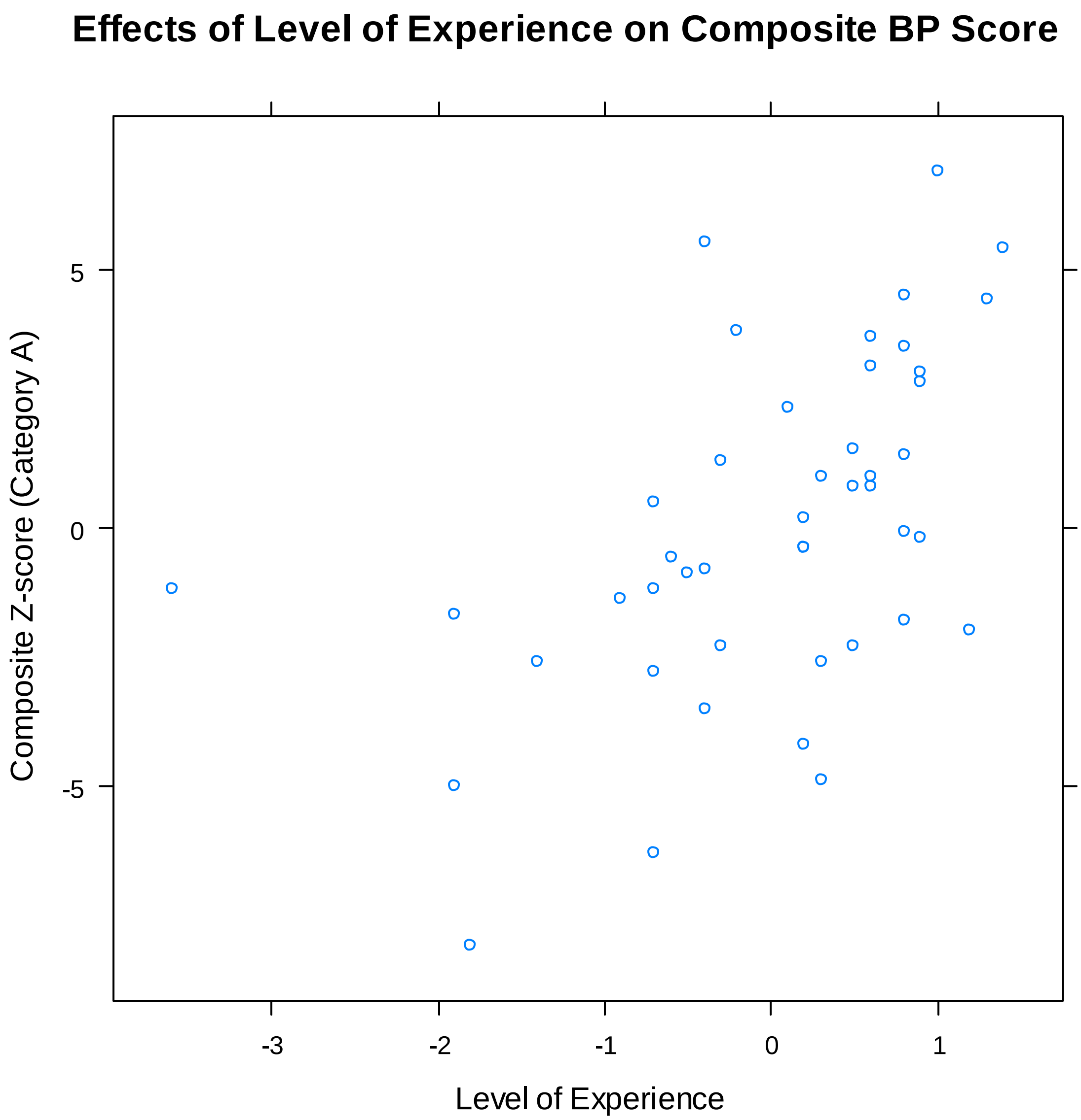


Figure 15: Level of experience vs. Composite Z-score

A student t-test was used to determine if there was a relationship between these two factors:

H_0: There is no relationship between the level of experience and the overall z-score of a BP ($\rho = 0$)

H_A: Level of understanding and the overall z-score of a BP are correlated ($\rho \neq 0$)

The results of the student t-test are shown below:

n = 45 ; df = 43 ; SE_{ρ}= 0.1299 ; Test statistic, t = 4.04; **p-value = 0.0002<<0.05**

Since the p-value is less than 0.05, the null hypothesis is rejected in favor of the alternative. Therefore, there is very strong evidence that the participant's degree of experience using the BP was correlated to the overall composite BP z-score.

Figure 14 and Figure 15 above show a strong positive correlation between both the degree of understanding and the level of experience and the overall Z-score awarded for the best practice. Therefore, the greater the experience the survey participant had using the BP , as well as the greater the understanding of the BP, the higher the overall score would typically be. While this observation does not change the fact that the top performing BPs are valuable, it does call into question the validity of the lowest ranking best practices. For example, PM-13: Use of Earned Value Analysis, had the lowest composite z-score of all 45 BPs at -8.1, but also had among the lowest levels of understanding and past experience. This low experience and understanding level and was supported by comments collected from the open-discussion questions. The most common response to earned value analysis was that it was 'too complex' and 'not easily understood.'

3.4.3 Conclusion and Recommendations

The original list of 45 BPs was developed by the CMSC based on years of experience with WisDOT operations. While all of these BPs likely have value in terms of ability to save cost and schedule on a project, it was originally hypothesized that not all would be applicable to as WisDOT department wide best practices. This hypothesis was further validated by the results of the BP workshop which clearly showed a difference in perceived value of each of the 45 BPs.

The BP workshop showed strong evidence for the importance of the top 9+2 best practices for the WisDOT. However, the results obtained from the survey represent a subjective first-pass study on best practices. It would be wise for WisDOT, or any SHA, to implement a metrics tracking system on each of its current BPs to determine the true cost-to-benefit ratio. Further, it is advised that each SHA evaluate and compare the 9 + 2 BPs to any formal best practices they may currently have in place as well as any future needs; any metrics data that an SHA already possesses for their BPs can be used as a comparison to validate the results obtained from this BP survey.

CHAPTER 4

ANALYSIS OF WisDOT ARRA DATA

4.1 INTRODUCTION

Two of the 45 best practices described in Chapter 3, PM-32: Prepare Project Benchmark Performance Indicators and FR-1: Implement a Project Financial Reporting System, were identified as having the potential of being highly effective best practices for WisDOT. To test this theory of effectiveness, a large amount of detailed project cost and schedule information would be required. Fortunately, the ARRA program was just reaching the end of its two-year duration and had a wealth of cost and schedule records. The research team was thus able to use this valuable resource to test whether the use of PM-32 and FR-1 were of benefit to the WisDOT.

Recall from Chapter 2 that all recipients of federal ARRA dollars were required to follow transparency requirements that mandated tracking of how those funds were allocated throughout the duration of each construction project. Adhering to these requirements, the WisDOT had each of its ARRA funded construction projects tracked both in terms of percent complete by cost (% Cost) and percent complete by time (% Time) on a monthly basis. These two variables of '% Time' and '% Cost' are analogous, respectively, to the EVA concepts of 'earned hours' and 'earned value' that was described in the literature review of chapter 2. Logically it would make sense for highway construction projects to follow a similar sigmoid curve as vertical construction industry. However, while formulas for S-curves have been developed for vertical construction, their application in highway, road, and bridge construction has yet to be seen in the literature.

Working in collaboration with the WisDOT, the CMSC received data on all Wisconsin ARRA projects up through February 2011, by which nearly all of the ARRA contracts let for bidding in 2009 and most of the smaller 2010 construction projects were fully complete. In addition to collecting monthly data on earned hours and earned value, the WisDOT also tracked numerous other variables (Table IX).

Table IX: WisDOT ARRA Project Reporting Fields

Variable	Description
Year	Year construction project was submitted for bid
State/Local	Whether the project was a state project or a local project
Region	WisDOT divides the state into five regions: North Central, North East, North West, South East and South West (See Figure 16 Below)
Construction ID	Each construction project had its scope of work divided into one or more manageable segments of work; these segments were given a unique construction ID; most construction projects had either one or two construction IDs, rarely were three construction IDs observed.
Description of Work	--
Award Amount	--
Current Construction Budget Amount	--
Construction Expenditures	--
% Time	Percent complete by Time
% Cost	Percent complete by Cost
Class Code	The type of construction was determined by using the 42 WisDOT three-digit class codes shown in Figure 34, APPENDIX C.1.

Figure 16: WisDOT regions for Wisconsin (WisDOT, 2011)

Upon receipt by the CMSC, the data collected by the WisDOT was 1) consolidated, 2) optimized for scope of research, and 3) analyzed for correlations and trends by the research team. Part of the consolidation process required that the research team limit its focus to a smaller subset of the data in order to remain within the research scope. The methods section of this chapter offers a complete description of the process used by the author to refine the original DOT data.

4.2 METHODS

4.2.1 Data collection

The '% Cost' value was calculated as:

Equation 1: Calculation of % Cost

$$\%\,Cost = \frac{Expenditures\ to\ Date}{Current\ Contract\ Award\ Amount}$$

Additionally, each construction project would have specified an original number of days to complete. The ‘Current Number of Days’ could then be calculated as:

Equation 2: Calculation of Current number of Days

$$Number\ of\ Days\ to\ Complete = (Date\ of\ Completion) - (Time\ Charges\ Start\ Date)$$

The ‘% Time’ value could then be calculated as:

Equation 3: Calculation of % Time

$$\%\,Time = \frac{Days\ Charged\ to\ Date}{Current\ Number\ of\ Days}$$

It is important to note that it is possible for change orders to affect both the award amount and the date of completion. Therefore, both ‘award amount’ and ‘current number of days’ were updated for *each* reporting month. Also, the data that was provided by the WisDOT had the % Time field already populated, which prevented the research team from any deeper investigations into this variable. All data provided by the WisDOT was collected by field personnel through their FieldManager© software. The data was then uploaded into their CAS application, which served as the WisDOT construction project tracking database. An example of the ‘% Time’ calculation using a screen-shot from the WisDOT CAS application is illustrated in Figure 17 below.

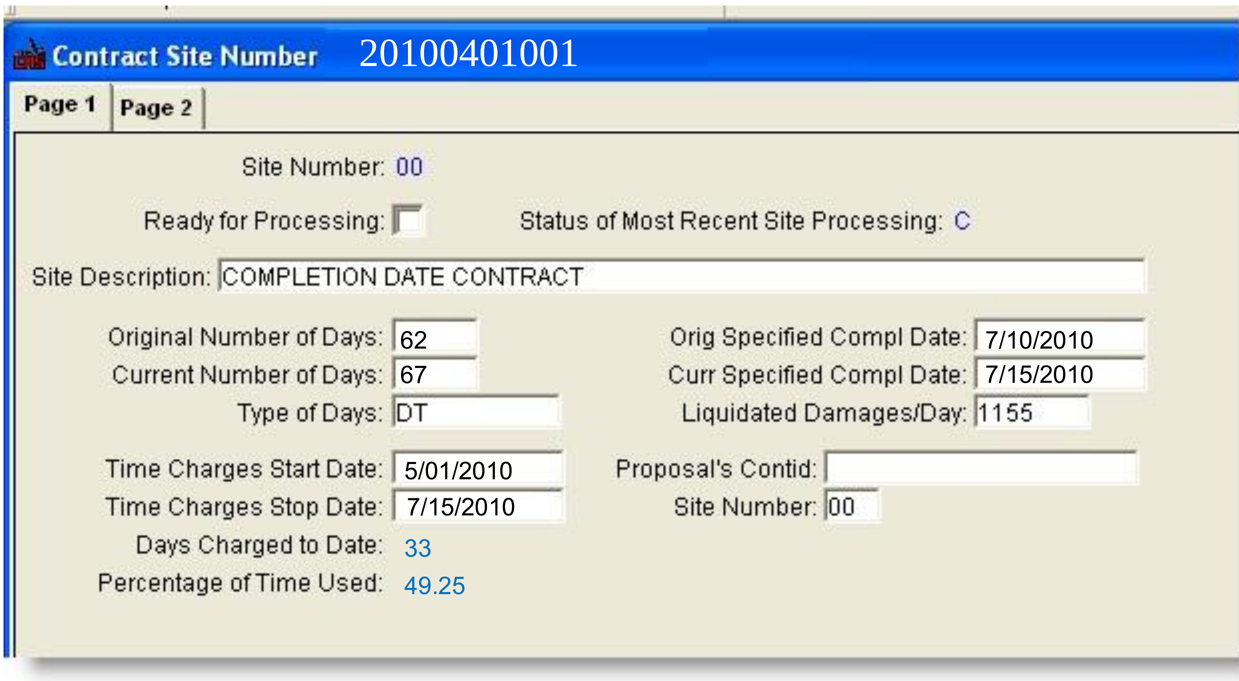


Figure 17: WisDOT CAS Project Tracking Application (Source: WisDOT).

In the example from Figure 17, the original contract specified 62 days to complete, for a completion date of 7/10/2010. However, a change order could have resulted in five additional days being added to the construction project. Thus, of the 67 days estimated for completion, 33 had been charged, resulting in a calculated % Time of 49.25%.

4.2.2 Data Consolidation

With the WisDOT data in hand, the first obstacle with the data was that it could not be analyzed at the finer resolution of the construction ID, but rather had to be looked at from the level of the construction project as a whole. The reason this had to be done was that the '% Time' field was tracked *only* at the construction project level and not at the construction

ID level. Therefore, within a construction project, time would begin running on all construction IDs concurrently regardless of whether work had actually begun on the other segments of the project. To work around this timing issue, the data was corrected so that all '% Cost' data was at the level of the construction project. This was accomplished by recalculating a new 'Award Amount', 'Current Budget Amount', and 'Construction Expenditures' for each construction project based upon the summation of the construction IDs within the project.

Equation 4: Recalculating % Cost based on construction project

$$\%\,Cost = \frac{\sum(Construction\ ID\ expenditures)}{\sum(Construction\ ID\ current\ award\ amounts)}$$

It is important to reiterate that the denominator in the % Cost equation above is *not* constant in time. Project change orders during the life of a project are not uncommon in any construction project, nor were they uncommon in the WisDOT data. To avoid having the expenditures exceed the award amount, the current award amount was thus recalculated for each monthly data point, otherwise expenditures would exceed the award amount and result in a '% Cost' > 100%. Recall that the '% Time' field did not have to be adjusted since it was being tracked at the level of the construction project anyway.

4.2.3 Data optimized for scope of research

Once the WisDOT data had been adjusted to the construction project level, 283 total contracts were identified; the break down is shown below in Table X along with a plot of all data points in Figure 18.

Table X: Summary of initial ARRA data

Category	# of Construction Projects
2009 State	43
2010 State	16
2009 Local	73
2010 Local	151

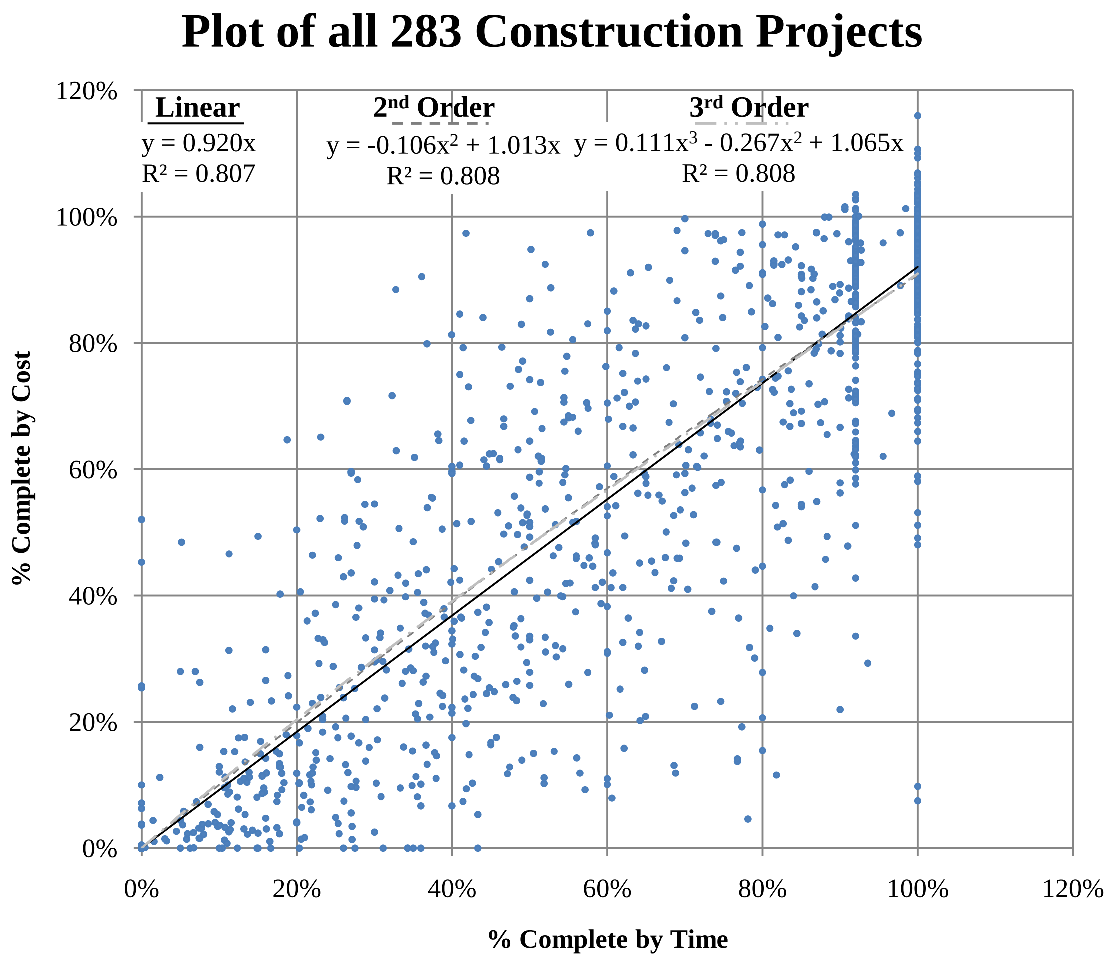


Figure 18: Regression Analysis of all 283 WisDOT ARRA Projects

The plot of all 283 construction projects in the figure above shows the data in its original form having only been adjusted to the level of the construction project, as previously described. Three different types of regression models are shown for comparison. Based on this comparison, higher order models appear only to increase the R^2 by a trivial amount. Also, a large number of data points were observed near 92% Time. Further investigation revealed that those 13 points represented the final reporting month for 13 construction projects (See Figure 19 below).

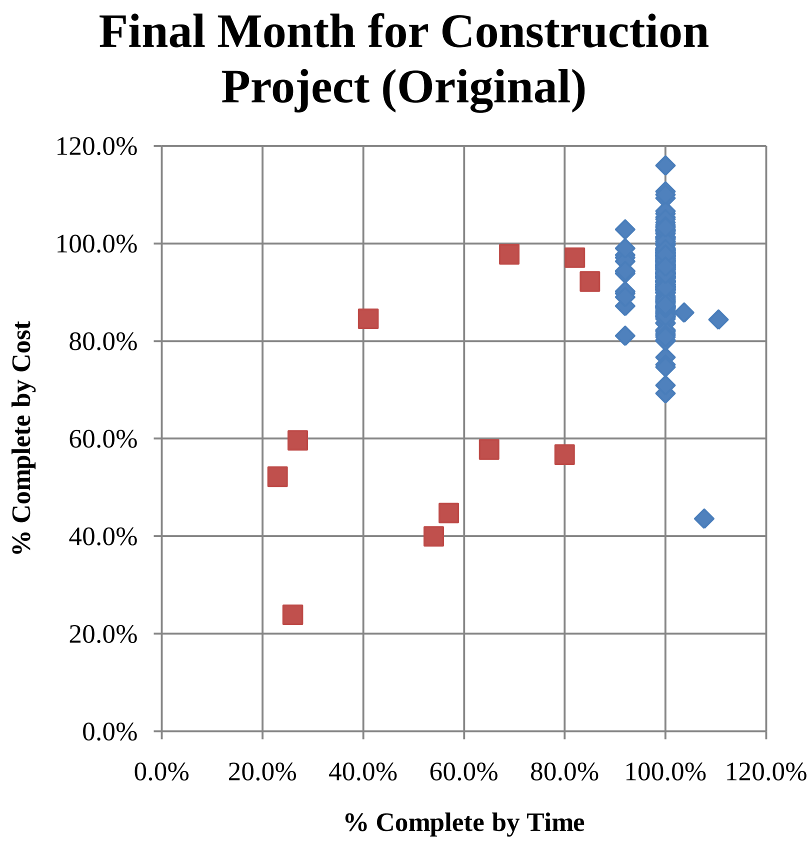


Figure 19: Plot showing 13 of the 283 construction projects with final '% Time' of 92%.

Also, Figure 19 above shows that three of the construction projects had '% Time' values above 100% while 11 had % Time values less than 92%.Therefore, the majority of the 92% Time data points of Figure 18 did not represent the terminus of construction projects, but rather was a common point in time among many projects that could be considered as representing substantial completion. Based on this observation, it was decided that construction projects not having reached at least 92% Time, 11 in total, would be excluded from the research study on the basis of being incomplete.

In addition to '% Time', construction projects not achieving at least 94% Cost were also eliminated (See Table XI below). The rationale for placing minimum thresholds on both '% Time' and '% Cost' was that the research team was interested in tracking *individual* construction projects from the start of construction through substantial completion. Having incomplete projects would not allow for this individual tracking methodology.

Table XI: Removing projects not achieving >94% Cost

Category	# of Contracts (Initial)	# of Contracts excluded (<94% Cost, <92% Time, or No Data)	# of Contracts Remaining
2009 State	43	13	30
2010 State	16	11	5
2009 Local	73	42	31
2010 Local	151	82	69
Total	283	148	**135**

Working within this initial list of construction projects, the focus turned to the monthly data points occurring near the start and end of each construction project. In nearly all cases, each construction project had several months of repetitive data points of 0% Time and 0% Cost preceding the start of construction (Figure 20). These particular data points were not of relevance to the research scope and therefore were removed to avoid distorting the best-fit model; recall that the research scope only focused on how % Time and % Cost correlated *following* the start of construction.

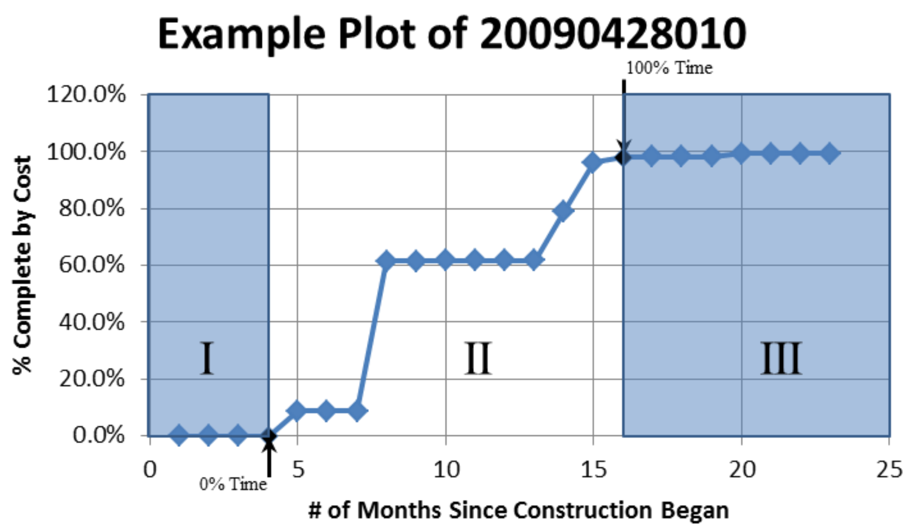


Figure 20: Typical construction project cumulative plot

It should be noted that cold winter months not typically associated with the Wisconsin construction season were still included in the data profile (i.e. November through March). However, further investigation revealed that the construction off-season was not responsible for the abrupt jumps in the % Time and % Cost plots.

Additionally, the repeating data points occurring after the contract reached 100% Time (region III of the figure above) were generally not of interest and were excluded, as they were just repeats of the months prior. However, to avoid erroneously removing contracts with schedule overruns, the '% Time' data was allowed to extend past the 100% mark so long as the '% Cost' increased at least 4% for that given month. The 4% requirement was subjectively chosen as a balance point; on one hand there was the risk of prematurely curtailing a project with actual punch-list and minor rework being performed, on the other hand there was the chance of allowing the project to continue for too many months following 100 % Time with no genuine work being performed. Thus, the 4% mark seemed a logical best assumption between the two extremes

For those construction projects allowed to extend past 100% Time, the final '% Cost' data point for that project was compared to the '% Cost' value at the first occurrence of the 100% Time data point. If the different between the those two '% Cost' data points exceeded 8%, then the construction project was flagged for further review to ascertain the potential causes for the delay in reporting. Again this 8% mark was a subjective value determined by the author.

In contrast to % Time, rarely did a construction project reach exactly 100% Cost, as is illustrated in Figures XX and XX below.

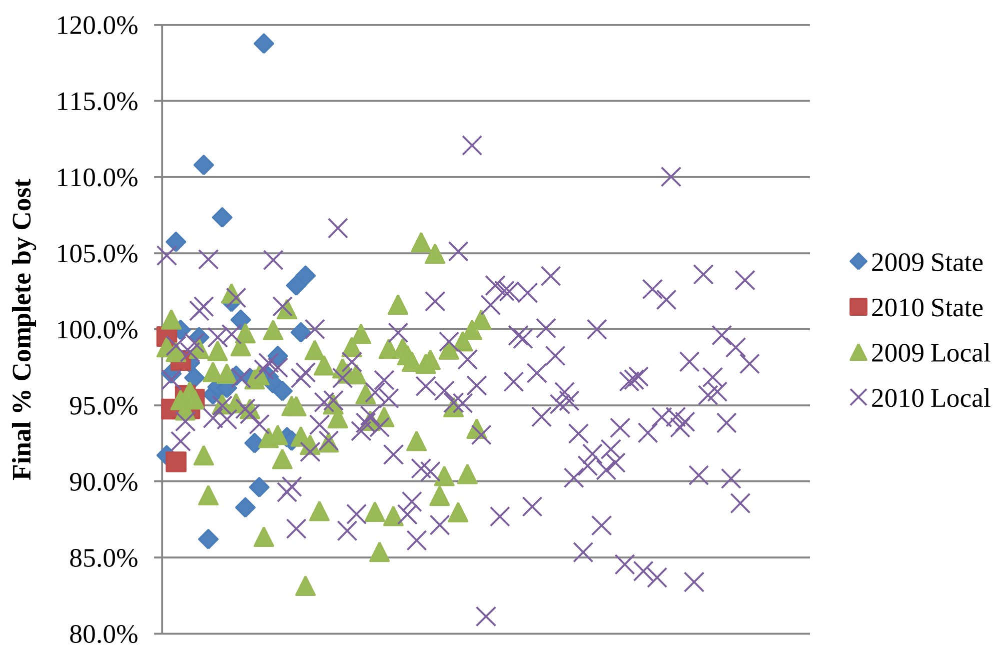


Figure 21: Final % Cost for all WisDOT ARRA projects

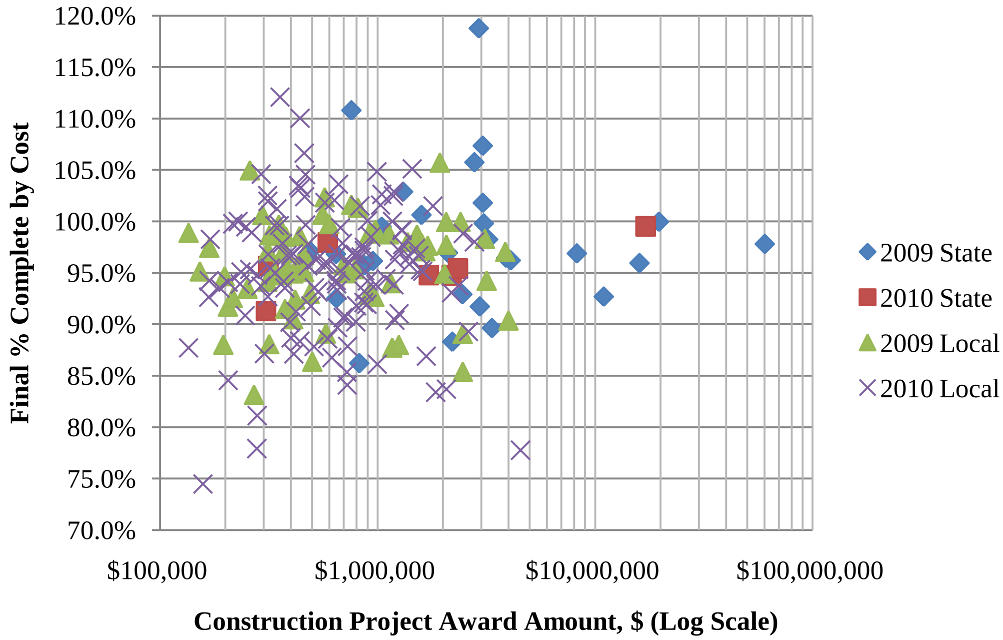


Figure 22: Final % Cost for all WisDOT ARRA projects based on award amount

It would be unusual for construction projects that were bid to come in either under or over budget unless there were other factors at play. Some of these reasons could be 1)change orders either reducing or increasing scope, 2) cost overruns, 3) retainage, or 4) data collection errors in the field. Retainage was withheld on each contract according to the Wisconsin Standard Specification of 5% of the last 25% (CMM, 2010). Also, the state engineer had additional control over the rate at which retainage was released as a contract approached substantial completion, so not all contracts would follow the same retainage payout rate. Regardless of the cause of these differences, it was decided that comparison between construction projects would be best performed if the projects had a standardized scale for both % Time and % Cost. Therefore, each construction project had its *final* % Cost value adjusted to 100%. Also the 13 projects that did reach only reached 92% Time were allowed to be adjusted to 100%. It should be noted that any adjustments to % Cost or % Time was *only* for the final month, any preceding data values for % Cost and % Time were not changed because that data was believed to be accurate at its time of reporting.

Lastly, recall from the literature review of Chapter 2 that plots of earned hours to earned value for electrical construction follow a sigmoid curve or S-Curve. Given certain similarities in the timing of productivity between electrical construction and highway construction, the research team originally hypothesized that an S-curve would best model the observed ARRA data. Therefore, it was important that each construction project be of sufficient duration so that a plot of the monthly data points would be capable of providing the necessary resolution required to fit polynomial and cubic regression functions. To decide on a cut-off point, a kernel-density plot of the 135 construction project durations was created (Figure 23).

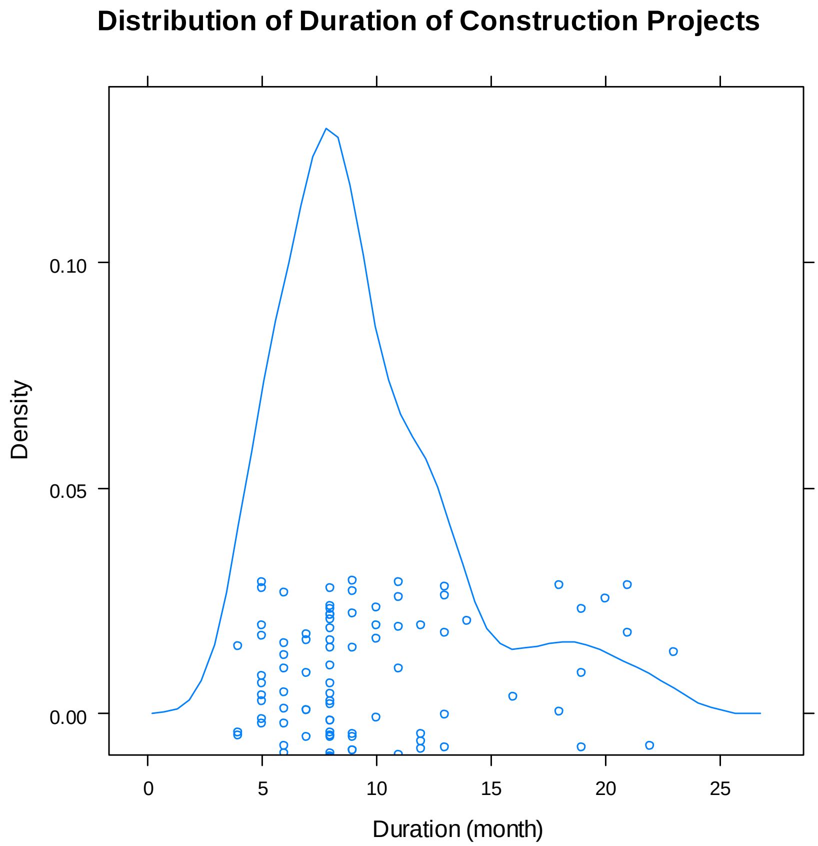


Figure 23: Plot of project duration for 135 projects; mean = 9.6 month, sd = 4.1 month

As is shown in Figure 23, many of the construction projects from the ARRA study had very few data points. It would be unreasonable to expect anything more refined than a linear model for those construction projects with so few data points. Subsequently, the author determined that at least 10 data points would provide both the resolution and accuracy need for modeling a realistic regression function. Unfortunately, the majority of the 135 contracts meeting the previous requirements of ≥94% Cost and ≥92% Time, had fewer than 10 data points. Additionally, two state contracts from 2009 were removed from the study because they showed a pattern of *decreasing* '% Time' from sequential months. This anomaly could have been a result of change order increasing the number of days for completion, but it also could have been erroneous data. To err on the side of caution, those few contracts were eliminated from the data pool. In the end, only 20 contracts remained (See Table XII below).

Table XII: Elimination of projects with fewer than 10 data points

Category	# of Contracts (Initial)	# of Contracts removed (≤94% Cost, ≤92% Time, or No Data)	# of Contracts removed (<10 data points)	# of Contracts removed due to decreasing % Time	# of Contracts Remaining
2009 State	43	13	20	2	8
2010 State	16	11	4	--	1
2009 Local	73	42	21	--	10
2010 Local	151	82	68	--	1
Total	283	148	113	2	**20**

Of the original 283 contracts, only 20 were selected based on having enough data points to allow accurate regression analysis. Those 20 contracts were then categorized based on whether their final contract award amount exceeded $5 million and also whether the contract was predominately a roadway or bridge contract (See Table XIII below).

Table XIII: Final 20 WisDOT construction projects

Contract Number	State or Local	Project Class Code	Class	Duration (months)	Region	# of Projects	Contract Award Amount
20090428006	State	ACF	Structure	18	SE	3	$19,628,254
20090428008	State	ABF	Structure	21	SE	3	$60,201,399
20090428010	State	H	Roadway	16	NC	1	$1,044,266
20090527016	State	AC	Roadway	19	NE	1	$8,240,792
20090527017	State	ACK	Roadway	17	NE	1	$3,900,000
20090527018	State	ACK	Roadway	20	NE	1	$3,221,080
20090527019	State	F	Structure	19	NE	2	$15,982,079

20090623006	State	ABC	Roadway	19	NE	1	$15,295,973
20100126026	State	AF	Structure	11	NW	2	$17,077,556
20090428021	Local	ADF	Structure	13	SW	1	$946,779
20090527009	Local	A	Roadway	14	SW	1	$2,070,332
20090623020	Local	AC	Roadway	16	NC	1	$1,519,459
20090623022	Local	AF	Structure	18	NC	1	$758,676
20090623023	Local	AF	Structure	12	NW	1	$1,129,628
20090623024	Local	A	Roadway	12	SE	1	$3,117,840
20090728003	Local	ABC	Roadway	17	SE	1	$1,936,000
20090728004	Local	AC	Roadway	15	SE	1	$2,073,900
20090728014	Local	ABD	Roadway	14	NC	1	$2,410,399
20090728015	Local	ADF	Structure	21	NC	1	$558,407
20100323010	Local	ABF	Structure	13	SW	1	$2,680,798

4.2.4 Data Analyzed for correlations and trends

Using principles of earned value analysis (EVA), '% Time' was graphically plotted against '% Cost' for each of the 20 construction projects. Then a series of regression functions were fitted to the model using the method of least squares. The regression models ranged from linear to fourth-order polynomial functions. In all cases the models were required to have a y-intercept of zero to account for the known starting point.

The regression models were compared to one another to determine which model best represented the data without convoluting the model with unnecessary and unrealistic variables. Using the statistic method of Analysis of Variance (ANOVA), the benefit of adding another term to the model vs. the cost of losing an extra degree of freedom was assessed via the F-statistic. The model with the greatest F statistic was the model that best explained the observed data.

4.3 RESULTS

From the 20 WisDOT construction projects, the initial hypothesis that the plot of % Time vs. % Cost would be sigmoidal was brought into question (See Figure 24).

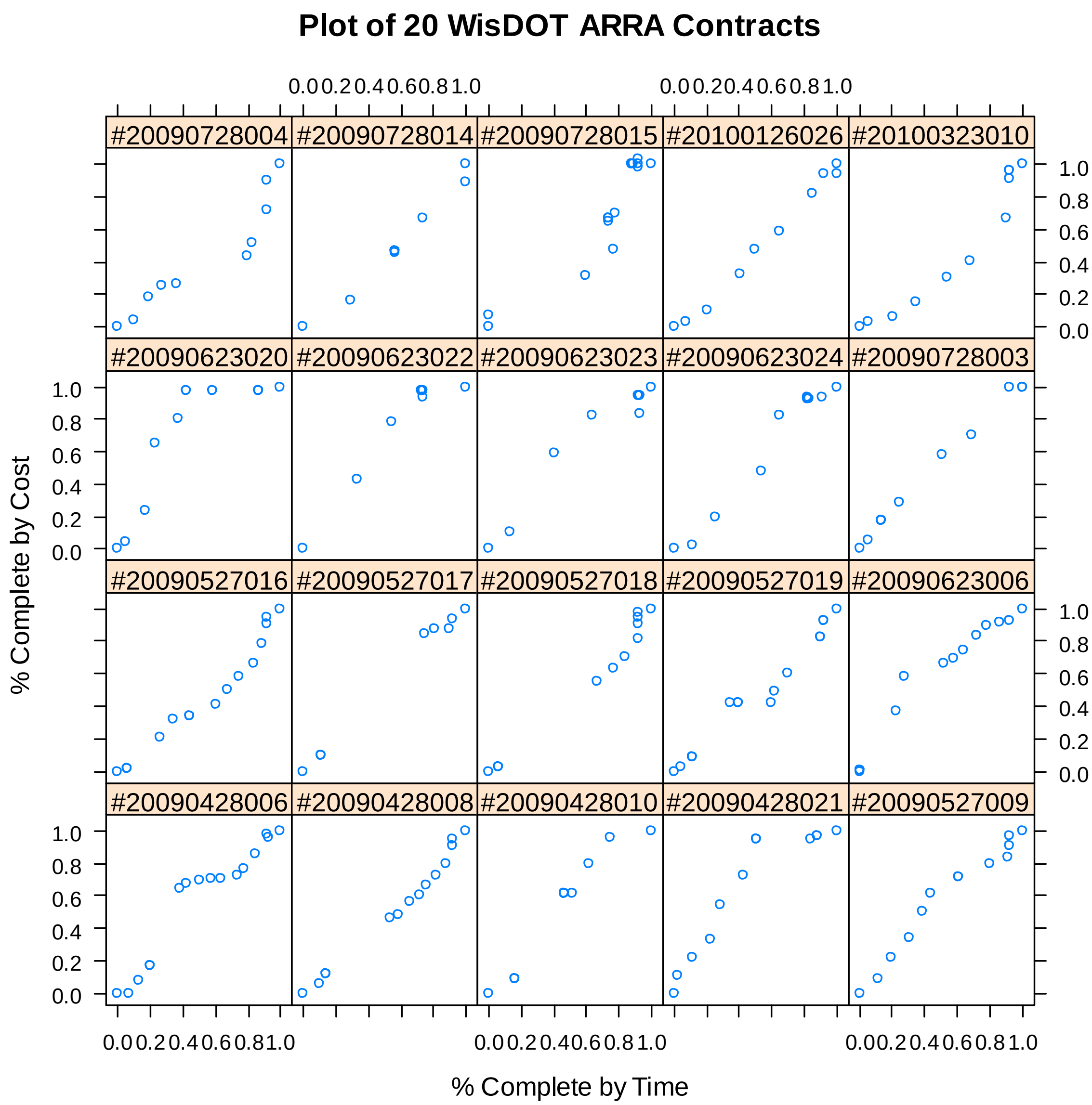


Figure 24: Cumulative process curves for 20 projects

Of all the contracts, there were only five that showed similarities to the sigmoid shape. One of those five contracts was #20090428010 (plotted in Figure 25 below).

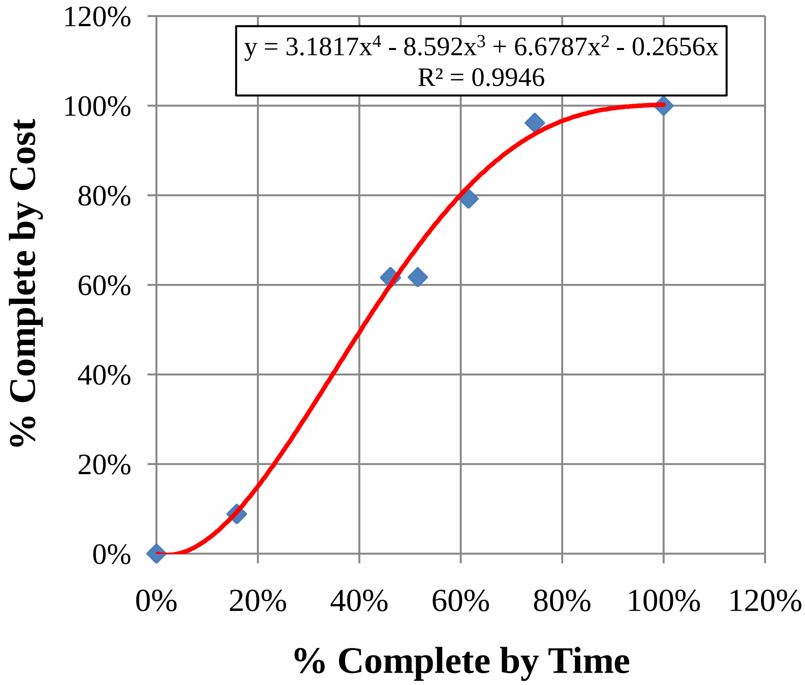


Figure 25: Construction project, 20090428010, with fourth-order regression

The ANOVA results indicate that even the fourth-order polynomial may be excessive, given its complexity in nature (Table XIX, Appendix C.2). Consider for example third-order polynomial function for the same construction project plotted in Figure 25 (Figure 26).

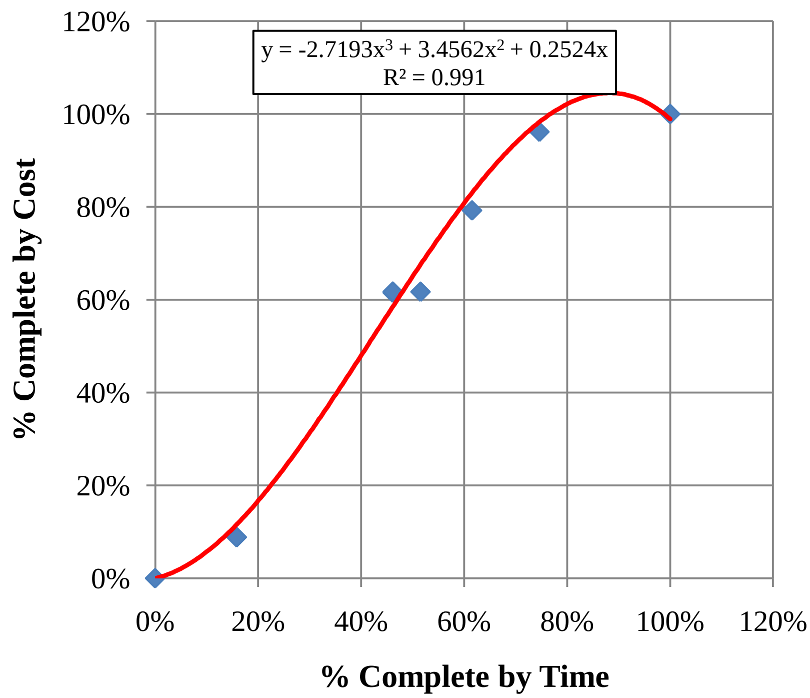


Figure 26: Construction project, 20090428010, with third-order regression

Additionally, the research team was interested in determining if there were differences in the regression curves for roadway vs. structures projects and also projects greater than $5 million and projects less than $5 million. Plots of these data comparisons are shown in Figure 27 and Figure 28 below.

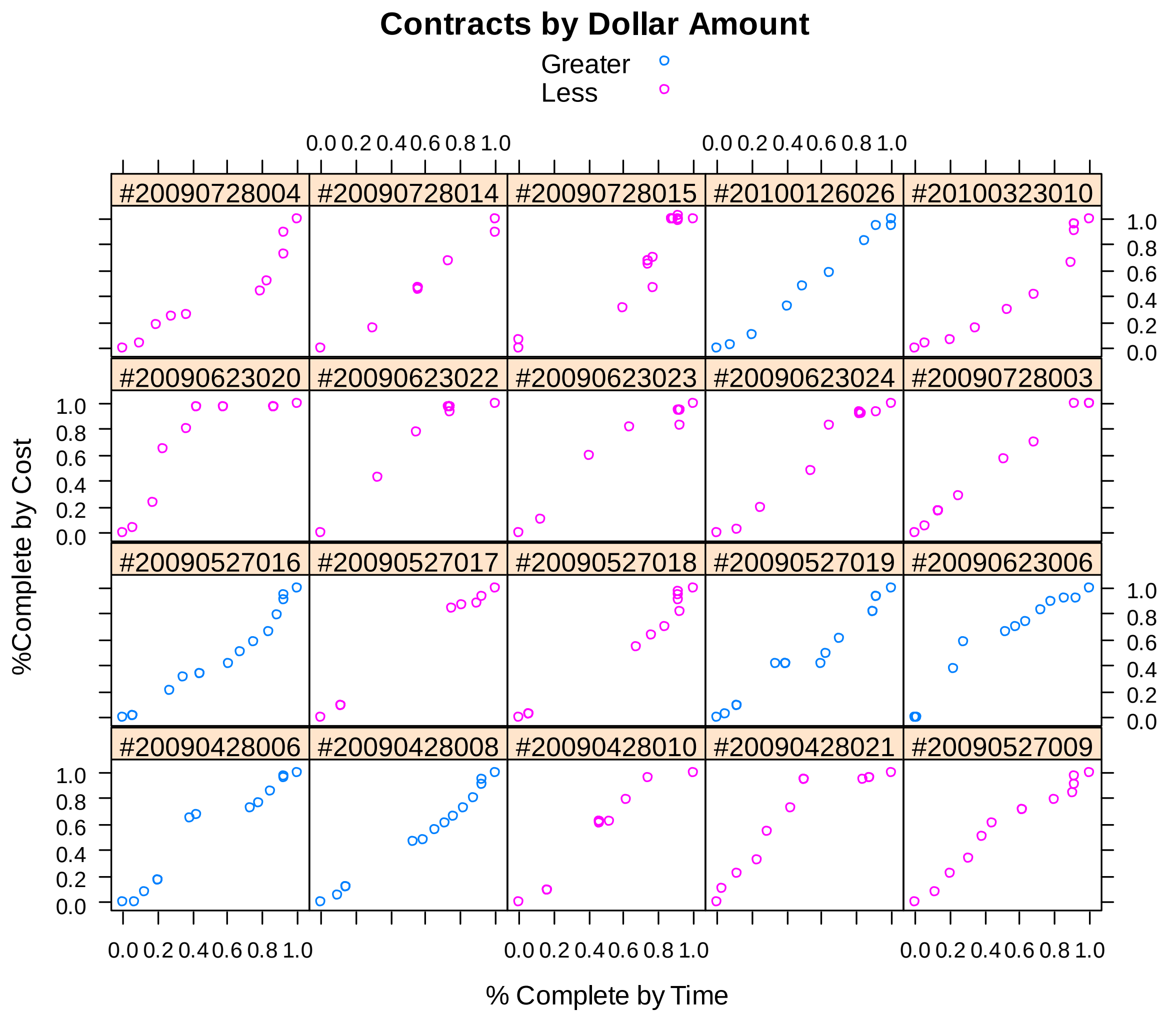


Figure 27: Comparison of 20 WisDOT projects by degree of expenditures

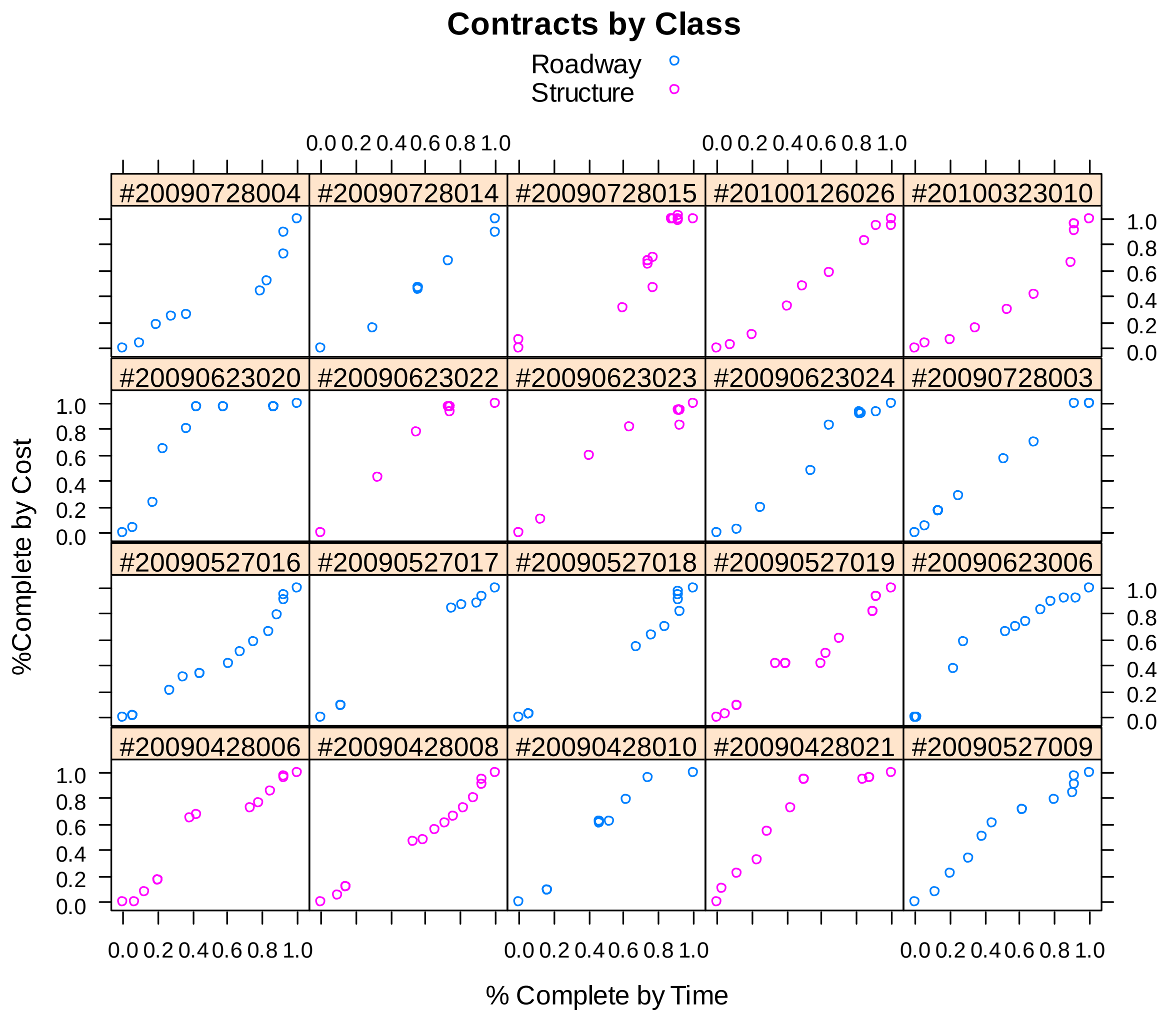


Figure 28: Comparison of 20 WisDOT projects based on project type

The results of the above comparisons showed no significant differences between the populations; therefore the selected 20 construction projects were combined and plotted as a whole (See Figure 29 below).

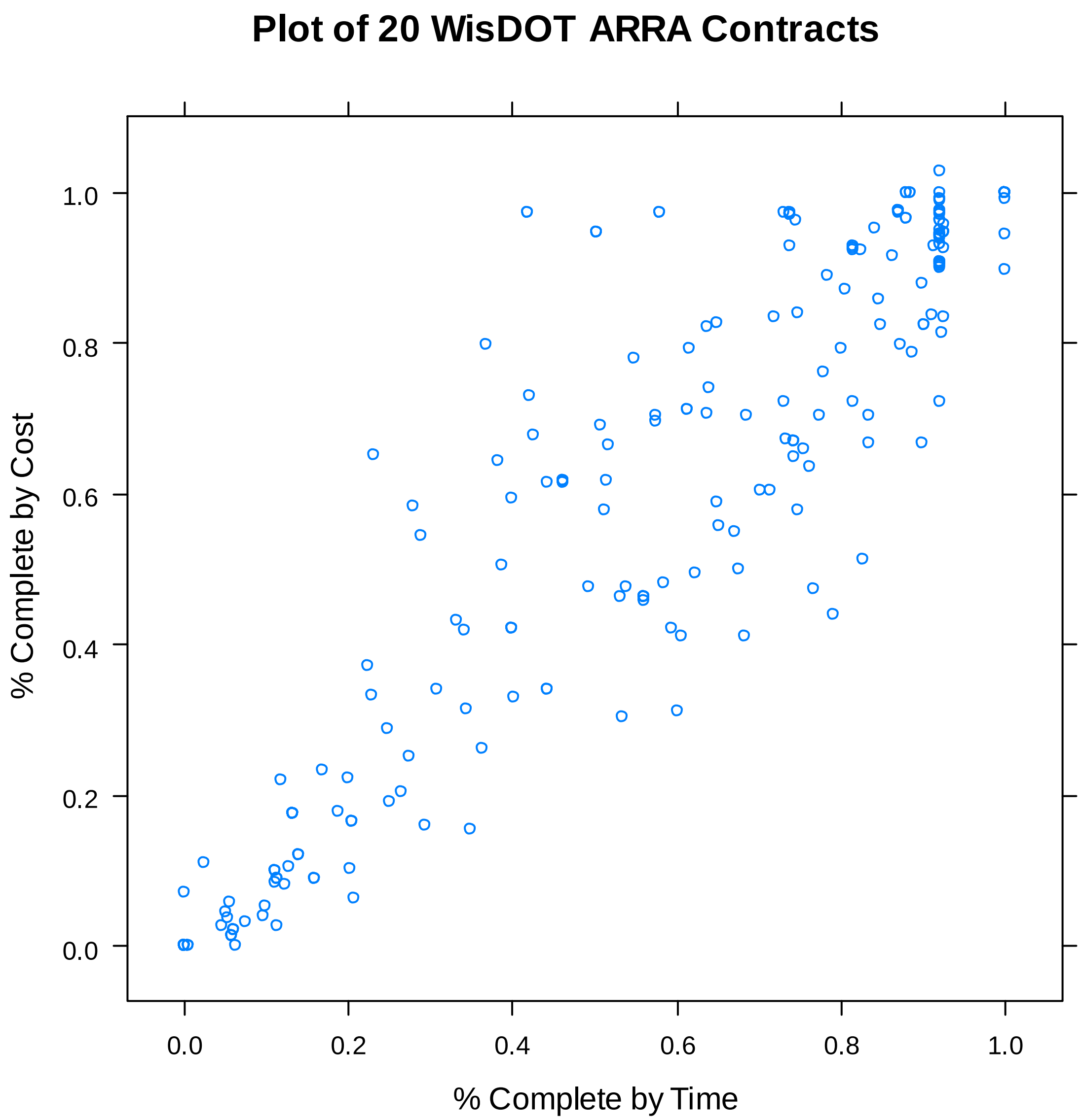


Figure 29: Combined plot of the selected 20 construction projects

Next, four regression models were fitted to the combined data and compared using the ANOVA technique as previously described (Table XX, Appendix C.3).

The output from ANOVA suggests that the optimum model would be a quadratic, second-order function. The coefficients, R^2 values, and degrees of freedom are shown in Table XXI, Appendix C.4. The calculated equation for quadratic model is:

$$\% \text{ Cost} = 1.290\ (\% \text{ Time}) - 0.309(\% \text{ Time})^2 + \varepsilon[\text{error}]$$

However, an alternative to plotting all the data points for all 20 contracts is to develop a series of control points at defined values of '% Time'. Previous research on EVA for electrical/mechanical contractors provided guidance on how to develop these control points (Hanna, Peterson, & Lee, 2002). The '% Time' axis was divided into 10% blocks. The '% Cost' and '% Time' values associated with those distinct blocks were then averaged and the standard deviation calculated for '% Cost' (See Table XIV below)

Table XIV: Control point data for the 20 selected construction projects

% Time Range	# of Data Points	Average % Time	Average % Cost	SD (%Cost)
0%	--	0.0%	0.0%	--
0% - 9.9%	18	5.1%	2.9%	2.7%
10% - 19.9%	26	13.5%	13.2%	5.1%
20% - 29.9 %	17	24.0%	28.3%	17.6%
30% - 39.9 %	18	36.7%	44.1%	17.9%
40% - 49.9%	25	44.4%	61.0%	20.4%
50% - 59.9%	24	54.9%	60.7%	20.7%
60% - 69.9%	17	64.4%	63.0%	16.3%
70% - 79.9%	30	74.7%	79.0%	17.2%
80% - 89.9%	29	85.8%	88.5%	12.0%
90% - 99.9%	37	92.0%	92.4%	7.4%
100%	--	100.0%	100.0%	--

The data in Table XIV was plotted along with upper and lower bound curves created by respectively adding and subtracting the standard deviation to the control point at each block of time (See Figure 30 below).

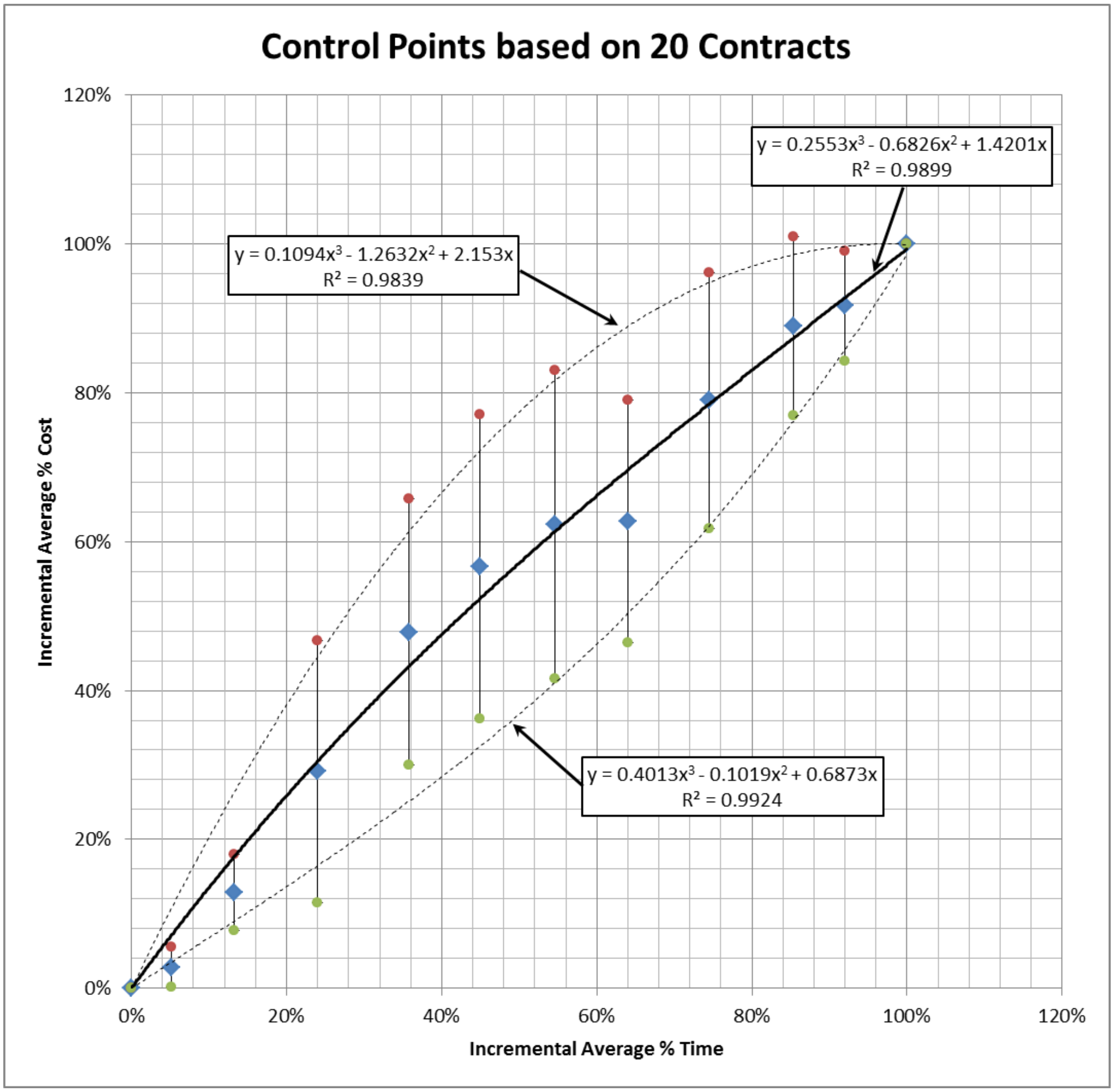


Figure 30: Plot of control points for the 20 selected construction projects

The observed data shows that the variance, or uncertainty, in the '% Cost' was greatest for the middle portion of the contract duration. Also, a cubic regression model shows a *greater* slope during the beginning and end of the construction phase, signifying periods of increased productivity, exactly opposite of what experts in construction productivity would suggest. This will be further discussed in the conclusion section.

As a data check, control points were also developed for the original 283 construction projects. The data and plot of the results are shown below in Table XV and Figure 31.

Table XV: Control point data for all 283 construction projects

% Time Range	# of Data Points	Average % Time	Average % Cost	SD (%Cost)
0%	--	0.0%	0.0%	--
0% - 9.9%	53	6%	14%	18%
10% - 19.9%	99	14.2%	12.8%	11.4%
20% - 29.9 %	106	24.5%	24.2%	18.5%
30% - 39.9 %	96	35.2%	33.4%	21.8%
40% - 49.9%	119	44.3%	44.5%	21.8%
50% - 59.9%	105	54.1%	53.6%	21.4%
60% - 69.9%	90	64.0%	56.7%	23.5%
70% - 79.9%	89	74.7%	69.1%	23.3%
80% - 89.9%	108	84.5%	76.2%	20.8%
90% - 99.9%	182	92.0%	84.1%	14.5%
100%	--	100.0%	100.0%	--

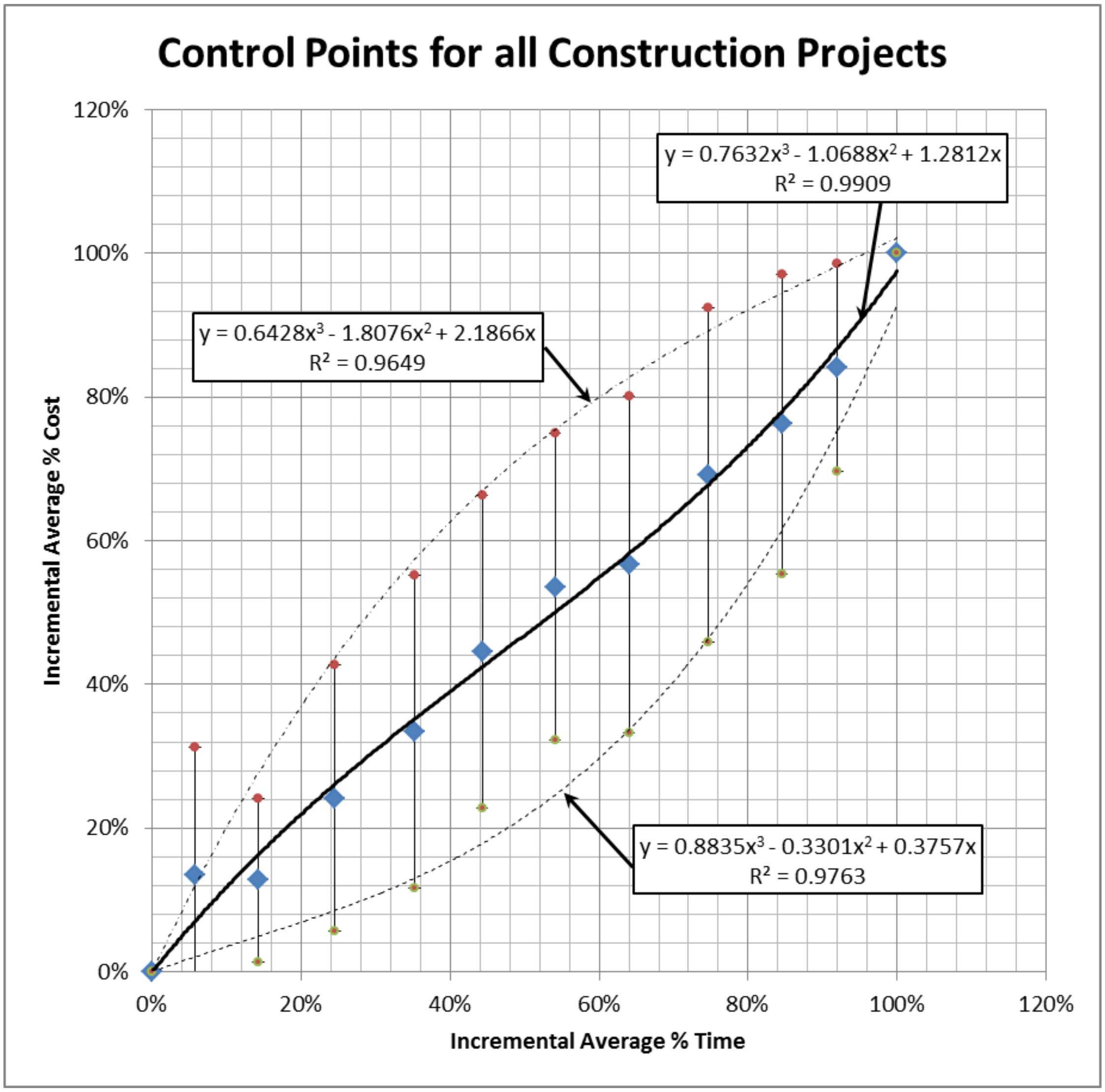


Figure 31: Plot of control points for all 283 construction projects

The control point plots for the 20 construction projects and the 283 construction projects both show similar shapes, namely higher slopes near 0% Time and 100% Time. Therefore, whatever is causing the peculiarity with the productivity rates is consistent across the entire data sample. However, the plot of 283 projects did have greater variance.

4.4 CONCLUSION

Best practices FR-1 and PM-32 were identified as possessing high potential for cost and schedule savings to a SHA. The federal government effectively mandated the use of FR-1on ARRA-funded contracts. The intent of the CMSC team was to utilize PM-32 in conjunction with the WisDOT ARRA database as a means of validating the hypothesis that highway construction earned value analysis would follow a similar sigmoid-curve as has been observed with electrical/mechanical contractors. However, while the data obtained through the WisDOT project tracking database was extensive, it still relied on personnel in the field to correctly interpret and enter the data. Also, the data entered did not go through a quality control or quality assurance process, thus errors may exist.

Many times, a contract would be removed on grounds of incomplete or erratic source data. In the end, only 20 out of 283, or 7.1% of all construction projects were selected as adequate for data analysis. Even with a small sub-sample of the 20 ‘best’ construction projects, there still were anomalies that could not be explained. For example, plots of the control points showed periods of maximum productivity occurring at the start and end of the contract, when logic suggests they should be at their lowest. This observation is so in contrast to the fundamentals of construction productivity that must be indicative of a model created from data that is not ideally representative of actual conditions.

Alternatively, the observed abnormality in productivity rates could be a combination of both the data and the model. While higher order regression curves reduced the sum of the squares of the residuals, as is expected in any model, it also introduced greater numbers of variables and complexity that may not be justified by the nature of the model. To prove this point, a simple linear regression function fit to the data showed a reasonable fit without unwanted complexity of a cubic model (Figure 32).

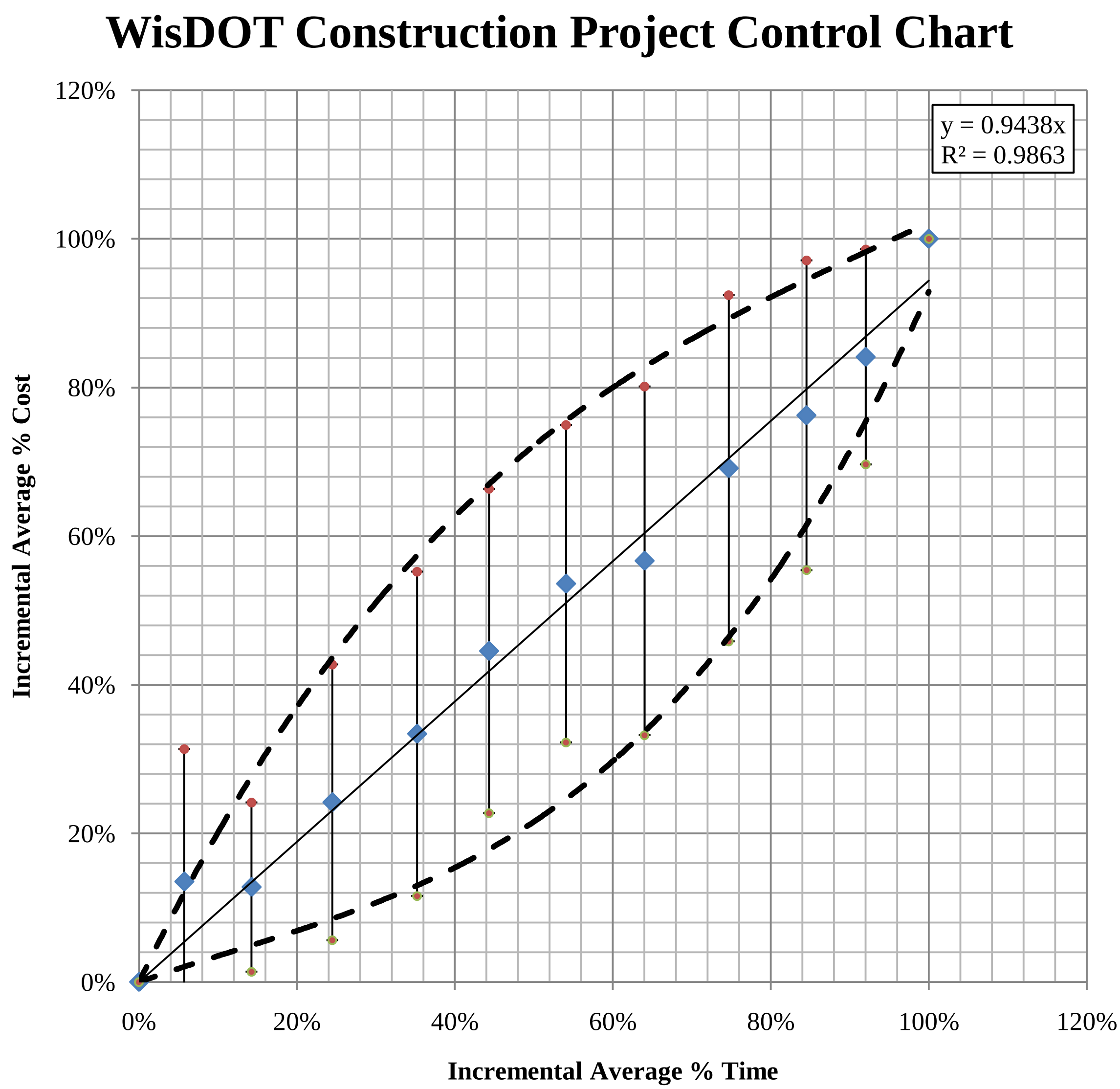


Figure 32: Linear regression model for construction project control chart

Thus a linear model may be the preferred model to use as-is without having to commit to additional education of staff pertaining to EVA. Furthermore, given that EVA is often misinterpreted as being overly complex and difficult to understand, a linear model may be the more practical solution, albeit slightly less statistically powerful.

However, while a linear model explains the observed data, the data itself may be misleading. For example, the linearity of the model may be a consequence of the timing of data collection. Short duration construction projects of only several months simply do not have a sufficient number of observations to be explained by anything other than a linear model. It is likely that weekly data reporting would be required if these small size projects are desired to be tracked in the future. However, the increased burden of collecting the data on small projects may not be justified by the anticipated benefits of the tracking. Therefore, it would fall to the SHA to weigh the anticipated cost vs. benefits on small scale ARRA/3R-type construction projects.

In summary, if the WisDOT chooses to continue implementing the its best practices on financial reporting and to also include the best practice on benchmarking project performance, then the data collection interval would have to be proportional to the project scope and all data collected would have to undergo some means of a QA/QC data review.

CHAPTER 5

CONCLUSIONS & FUTURE RESEARCH

5.1 SUMMARY

The literature review of chapter 2 stressed the need for and the benefit that performance measuring and benchmarking can have for a management team. Chapter 3 then took an in-depth look into 45 possible best practices covering a range of four areas of construction. This list of 45 was reduced to a list of nine common best practices for general construction projects plus an additional best practice specifically for Mega projects and another specifically for ARRA/3R projects. Chapter 4 provided a real world example of two of the higher ranked best practices from chapter 3—PM-32: Prepare Project Benchmark Performance Indicators and FR-1: Implement a Project Financial Reporting System. Data collected from the WisDOT ARRA database was used to track each construction project on two performance metrics, percent complete by cost and percent complete by time. This method of comparison between these two metrics touched on a third best practice, PM-19 Use of Earned Value Analysis. Specifically, the cumulative process curve, or S-curve, between these two metrics showed a plot that was more linear than sigmoid. In fact, given the resolution power of the data, a linear model was shown to be the best fit. However, the legitimacy of the ARRA data was brought into question each time an erroneous data point was discovered. Clearly a quality control and quality assurance program needs to accompany any data collection process.

5.2 CURRENT RESEARCH ON SCHEDULE FORECASTING

The literature review of chapter 2 clearly showed the abundance of research on the methods for budget and schedule forecasting and also highlighted the value these tools provide to the project management team. Moreover, this research paper has demonstrated the need for such forecasting capabilities. The next few sections will take a quick look into the current research being performed on forecasting methods. One such recent investigation by Kim and Reinschmidt is detailed below and presents a novel and intriguing look into the potential future of schedule forecasting.

EVM is based on the fundamental principle that "past performance is the best available indicator of future performance" (Kim & Reinschmidt, 2010). However, the accuracy of EMV forecasting is entirely dependent upon the accuracy of the performance measures used to measure past performance. Thus it makes it difficult for the project management team to distinguish between reliable and unreliable predictions of performance indicators for cost overruns and schedule delay.

It is paramount to a project's success that the project management team has the ability to accurately and reliably forecast a project's budget and schedule performance. EVA is recognized as a workable means for forecasting cost performance on construction projects; however, EVA's capacity for schedule performance forecasting is hindered due to its poor accuracy in predicting project durations (Kim et al., 2010). Every project has a certain level of inherent uncertainty, some more than others. The two ultimate limitations of EVA-based cost and schedule forecasting are: 1) EVA-based formulas are deterministic, meaning they do not account for the possibility of error, and 2) EVA-based forecasting methods are typically most unreliable in the early stages of a project (Kim et al., 2010). These two limitations are serious and worth further investigation.

As a potential solution, Kim and Reinschmidt propose an alternate method of schedule forecasting by coupling the earned schedule method (ESM) with the Kalman filter to form the Kalman filter forecasting method (KFFM). It should be noted that ESM uses the same performance metrics as EVM, but uses the dimension of time rather than value. Additionally, the mathematic theory behind the Kalman filter is beyond the scope of this paper, but its basic function is to act as a recursive algorithm "to estimate the true but hidden state of a dynamic system in the presence of noisy observations" (Kim et al., 2010). In the end, the KFFM provides a consistent schedule forecasting method by incorporating probability and prior performance information to correct for uncertainty and measurement errors in the ESM parameters.

Preliminary testing and initial comparisons suggest that both ESM and EVM are more inconsistent in their forecasts than KFFM. Moreover, ESM and EVM are particularly unreliable early in a project, before the performance efficiency factor stabilizes (Kim et al., 2010). Additionally, the KFFM is capable of attaching a probability of on-time completion for wide range of scenarios; something that ESM and EVM cannot (Kim et al., 2010). The KFFM is also fairly simple to use and is available as a Microsoft Excel® Add-on.

The enhanced accuracy and predictive flexibility of KFFM make it desirable as a project management instrument. However, the KFFM is still a very new application that will need to be vetted across a wide range of construction project sizes and types. For now, the

KFFM presents an interesting prospect at what may someday be a powerful tool in cost and schedule forecasting.

5.3 RECOMMENDATIONS

A great wealth of data was collected and analyzed as part of this research effort. The extensive data analysis from chapters 3 & 4 has brought about questions, answers, and recommendations for how WisDOT could improve upon its i) performance tracking, ii) its best practice management, and iii) the continuing technical education of its staff. In fact, these are the three key subject areas that any SHA should review and plan for prior to implementing any best practices program. The next several sections will take a brief look into each of these three recommendation areas.

5.3.1 Implementing a best practice program

First, the results from chapter 3 provide a good list of eleven best practices that the WisDOT, or any similar SHA, could further investigate as potential standard department practices on construction projects. While all eleven best practices showed great potential based on subjective survey results, it would be prudent practice to validate those results with quantitative data. It would be up to the SHA to decide if a best practice requires additional research on anticipated costs and projected value or if the data warrants the initiation of a pilot best practice study.

5.3.2 Implementing a performance measurement system

If a pilot study is to be implemented, it is paramount that the SHA have a formal performance metric system in place. The results from chapter 4 demonstrate how an uncertain measurement methodology can negatively impact the data study. Recall from chapter 4, that of the initial 283 construction projects, only 20 were selected based on quality and quantity of the data; the majority of the other construction projects were removed from the data for having erratic or otherwise improbable data results.

The WisDOT ARRA data did not appear to have a strong QA/QC process in place. The reasons for the observed poor data could be twofold. First, those responsible for the data collection may not have been properly qualified to collect the data. It is critically important that personnel responsible for performance measurement data collection receive proper education and fully understand the importance of what they are doing. Second, those responsible for the measurement may not have had adequate time or resources to collect the data properly. Heavy construction field staff typically already has heavy workloads (Whited 2007). Consequently, adding additional responsibilities can quickly become overwhelming and reduce worker morale and the quality of the data. As an alternative to lessen the burden on the field staff, the performance measures could be taken directly from project records via a software program; however, at least one person would still be required to validate the data to account for human error during data entry. Data validation sampling would have to be performed at a reasonable frequency. The frequency of sampling could be determined using simple statistic methods based on a predetermined confidence interval. Regardless of the cause of the erroneous data, the point is that there should be at least some form of a quality control/ quality assurance process in place with any data collection activity.

In summary, the rationale behind benchmark metrics, and the performance measures that support them, reduces down to the basic adage ‘what gets measured gets managed.’ A SHA should not be exempt from driving continuous improvement. Furthermore, there may come a time when certain types of federal funding become contingent upon using performance measures. Required or not, performance measures, benchmarking, and best practices are good business practice. However, their successful implementation requires a project management team that utilizes good communication practices; in the end, it all relates back to communication, teamwork, and leadership.

5.3.3 Continuing Technical Education

The results of chapter 3 showed a statistically significant relationship between the prior knowledge and experience of the survey participant and the overall rank given to a best practice. The validity of those top ranked, generally well-understood best practices is not being questioned. Rather, it is the less understood best practices that may have been scored poorly purely on lack of familiarity. One example would be best practice PM-13: perform project Earned Value Analysis. The survey results ranked EVA dead last out of the 45 best practices. However, the volume of literature endorsing some form of EVA makes it difficult and unrealistic to conclude that EVA should not be used on construction projects. What then is the source of the divide between academia and industry? The answer likely lies with human behavior; it is common to fear that which is not well understood. Therefore, EVA’s initial learning curve is likely the reason for its erroneous perception among SHAs as being overly complex and unwieldy in project management. The solution to this dilemma would be something akin to a promotion ad campaign involving the continuing education of the project management team. Moreover, the new ideas and advanced research being performed at academic institutions should not be sequestered from industry, but rather should be shared through collaborative efforts. While these collaborations do occur, one example of which is this research paper, they ultimately need to occur with much greater frequency.

5.4 FUTURE RESEARCH

The results from the best practices survey provided a valuable overall look into prospective best practices for use on heavy construction projects. However, subjective survey analysis results cannot guarantee the success of a SHA's best practice program. Rather, it would be recommended to expand the scope of the best practices survey to include real-world performance metric data from multiple SHAs, perhaps in a partnership with NCHRP. If collected accurately, this qualitative data could provide a much higher degree of explanatory power. The next step would be to initiate a pilot study and collect performance data to track each best practice.

Also, the S-curve study of chapter 4 could be repeated but with greater QA/QC of the data. Additionally, sampling of small construction projects of only 3-4 months duration would have to be done more frequently than each month. At a minimum, weekly estimates of both percent complete by time and percent complete by cost would have to be performed to yield adequate data resolution. However, this additional sampling would require additional funding for the project management team. In the end, a balance point would have to be reached based partly on educated assumptions and partly on the actual experience of the SHA.

APPENDIX

APPENDIX B

B.1 Example BP Description

PM-9 Establish project Close-Out Procedures early in project and track progress

Description:

Establish project close-out procedures with the contractor early in the construction phase project. Develop process for partial acceptance leading to final acceptance. Require the contractor to submit a schedule for completion of punch-list items. Conduct periodic review of preliminary finals to expedite final closeout items. Identify close-out items that can be worked on simultaneously or in parallel acceptance. Track closeout progress and assign action items as needed.

Additional Details:

Reviews of the finals progress/milestones should be done monthly until the process is essentially complete then quarterly until the project is closed.

Objective:

Primary: Schedule Control
Secondary: Issue Management

When to Apply:

Best practices should be applied on mega projects, backbone and large 3R projects or any project where traffic impacts economic activities.

Cost Implications:

No significant cost implication.

Conditions for Successful Application:

While the standard specifications define substantially complete, each project's unique circumstances and criteria should be discussed and agreed upon early in the project.

Cautions:

Poor definitions of project completion must be taken into account to prevent increased costs and time.

Figure 33: Example BP Description, PM-9

B.2 BP Averaged Survey Response Scores

Table XVI: Average scores, mean, and SD for all BPs and question types

Average Scores									
	Question								
BP	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
CM-1	2.8	3.4	2.8	3.7	3.9	4.0	2.9	3.0	2.3
CM-2	2.7	2.9	3.0	3.3	3.0	3.3	1.8	2.6	2.4
CM-3	2.5	2.7	3.0	3.4	3.3	3.6	2.6	2.4	1.9
CM-4	2.9	3.3	3.1	4.0	4.0	3.8	2.9	2.2	2.1
CM-5	2.9	3.1	3.0	3.4	3.3	3.3	2.2	2.4	2.2
CM-7	2.8	2.8	2.9	3.4	3.5	3.7	2.5	2.6	2.4
DC-1	2.7	3.1	2.9	3.3	2.9	3.6	2.3	2.9	2.8
DC-2	2.7	3.2	2.9	3.5	3.5	4.0	3.2	2.5	1.8
DC-3	2.7	2.8	2.6	3.5	3.3	3.4	2.3	3.0	3.0
DC-4	2.5	2.7	2.7	2.7	2.5	2.6	2.0	3.0	2.6
DC-5	2.4	2.7	2.7	3.5	3.5	3.7	2.9	2.7	2.6
DC-6	2.3	2.1	2.9	3.0	3.1	3.3	1.9	2.5	2.0
FR-1	2.2	3.1	2.8	3.6	4.0	3.8	2.9	2.7	2.5
FR-2	2.5	3.1	2.9	3.6	3.7	3.6	3.1	2.6	2.1
PM-1	3.0	3.6	2.8	3.9	4.0	3.9	3.3	1.9	1.5
PM-2	2.9	3.2	3.2	3.8	3.8	3.9	2.8	2.0	2.1
PM-3	2.9	3.2	3.1	3.4	2.9	3.3	1.9	2.5	2.6
PM-4	2.8	2.9	3.0	3.7	3.4	3.7	2.4	2.2	2.1
PM-5	2.7	2.7	2.6	3.6	3.5	3.6	2.2	2.7	2.4
PM-6	2.8	2.9	2.8	3.8	3.5	3.8	2.7	1.8	1.7
PM-7	2.9	2.4	3.2	3.2	3.2	3.3	2.2	3.1	2.2
PM-8	2.9	3.1	3.0	3.6	3.4	3.8	2.4	2.4	2.5
PM-9	2.8	3.4	2.9	3.9	3.9	3.9	3.6	2.1	1.5
PM-10	2.9	3.3	2.5	4.2	4.0	3.5	1.6	3.0	2.6
PM-11	2.8	3.3	3.0	3.8	4.1	3.9	3.0	2.7	2.3
PM-12	2.8	3.3	2.5	3.5	3.4	3.5	2.8	2.2	2.1
PM-13	2.3	2.2	2.5	2.7	2.6	3.2	1.6	3.5	2.8
PM-14	2.9	3.1	2.5	3.8	3.9	3.9	3.1	2.6	1.8
PM-15	2.6	2.6	2.9	3.5	3.3	3.3	1.9	2.5	2.6
PM-16	3.0	3.4	3.1	4.2	4.1	3.9	3.3	1.8	1.4
PM-17	2.9	3.6	3.0	3.8	3.7	3.7	2.6	1.7	1.7
PM-18	2.6	2.1	3.0	2.5	2.4	2.6	1.3	2.5	2.3
PM-19	2.3	1.4	1.4	3.0	3.0	3.5	2.5	2.4	1.8

PM-20	2.7	3.3	2.5	3.9	3.7	3.7	2.7	2.0	1.8
PM-21	2.6	2.8	2.9	4.0	3.8	3.9	3.4	1.8	1.5
PM-22	2.8	3.1	3.1	3.3	3.3	3.5	1.9	2.9	2.5
PM-23	2.6	2.8	2.4	3.2	3.2	3.4	2.4	2.6	1.8
PM-24	2.7	3.4	2.7	4.0	4.0	3.8	3.2	2.4	2.2
PM-25	2.9	3.4	3.2	3.9	4.0	3.5	2.3	2.9	2.9
PM-26	2.5	2.7	2.7	2.9	2.8	3.2	2.2	2.6	2.1
PM-27	2.8	3.4	3.1	3.3	3.3	3.4	2.8	2.7	2.4
PM-28	2.8	3.4	3.0	3.8	3.7	3.9	3.0	2.1	1.9
PM-29	2.9	3.2	3.0	3.4	3.4	3.8	3.1	2.3	1.6
PM-30	2.9	3.5	2.8	2.9	2.8	3.0	2.7	2.7	1.5
PM-31	2.7	3.1	3.3	3.3	2.9	2.8	1.4	3.2	2.7
Mean	2.72	2.99	2.83	3.50	3.43	3.54	2.53	2.50	2.16
SD	0.19	0.44	0.31	0.39	0.46	0.35	0.56	0.41	0.42

B.3 BP Survey Response Z-Scores

Table XVII: Z-scores calculated from average scores of Table XVI

Z-Score									
BP	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8*	Q9*
CM-1	0.2	0.8	-0.1	0.6	0.9	1.2	0.6	-1.2	-0.4
CM-2	0.1	-0.3	0.5	-0.6	-0.9	-0.8	-1.3	-0.3	-0.5
CM-3	-1.1	-0.7	0.5	-0.1	-0.4	0.1	0.2	0.4	0.6
CM-4	0.8	0.8	0.7	1.3	1.2	0.7	0.7	0.7	0.2
CM-5	1.0	0.2	0.7	-0.3	-0.2	-0.8	-0.7	0.3	-0.2
CM-7	0.2	-0.5	0.0	-0.2	0.2	0.4	-0.1	-0.3	-0.6
DC-1	0.1	0.2	0.3	-0.6	-1.2	0.3	-0.4	-0.9	-1.5
DC-2	0.1	0.5	0.1	-0.1	0.2	1.3	1.1	-0.1	0.8
DC-3	-0.3	-0.4	-0.7	-0.1	-0.2	-0.4	-0.4	-1.2	-1.9
DC-4	-1.3	-0.7	-0.5	-2.0	-2.1	-2.7	-1.0	-1.2	-1.0
DC-5	-1.5	-0.7	-0.3	0.0	0.2	0.5	0.6	-0.5	-0.9
DC-6	-2.0	-1.9	0.3	-1.3	-0.7	-0.8	-1.1	-0.1	0.4
FR-1	-2.6	0.2	0.0	0.2	1.2	0.6	0.7	-0.4	-0.8
FR-2	-1.0	0.3	0.2	0.3	0.7	0.3	1.1	-0.1	0.1
PM-1	1.5	1.4	0.0	1.0	1.2	1.2	1.3	1.5	1.6

PM-2	0.7	0.6	1.2	0.8	0.8	1.0	0.6	1.2	0.3
PM-3	0.9	0.5	0.7	-0.2	-1.1	-0.6	-1.1	0.1	-1.1
PM-4	0.4	-0.3	0.5	0.5	-0.2	0.5	-0.2	0.7	0.2
PM-5	-0.1	-0.6	-0.9	0.4	0.1	0.1	-0.6	-0.4	-0.7
PM-6	0.5	-0.2	-0.1	0.7	0.2	0.7	0.3	1.6	1.2
PM-7	0.7	-1.4	1.1	-0.8	-0.5	-0.8	-0.6	-1.3	0.0
PM-8	0.8	0.2	0.5	0.2	0.0	0.7	-0.2	0.2	-0.8
PM-9	0.5	0.8	0.0	0.9	1.0	1.0	1.9	0.9	1.7
PM-10	0.7	0.6	-1.2	1.8	1.1	-0.1	-1.6	-1.1	-1.1
PM-11	0.2	0.8	0.4	0.7	1.5	0.9	0.8	-0.5	-0.2
PM-12	0.7	0.6	-1.1	0.1	0.0	-0.2	0.4	0.8	0.1
PM-13	-2.3	-1.8	-1.2	-2.1	-1.9	-1.1	-1.7	-2.5	-1.6
PM-14	0.7	0.1	-1.2	0.8	0.9	1.0	1.1	-0.3	0.9
PM-15	-0.6	-0.9	0.3	0.0	-0.4	-0.6	-1.1	0.0	-1.0
PM-16	1.5	1.0	0.9	1.7	1.6	0.9	1.4	1.9	1.8
PM-17	1.0	1.3	0.5	0.7	0.5	0.5	0.1	2.0	1.2
PM-18	-0.6	-1.9	0.5	-2.4	-2.3	-2.9	-2.2	0.0	-0.2
PM-19	-2.2	-3.6	-4.6	-1.3	-0.9	-0.1	-0.1	0.1	0.8
PM-20	0.1	0.6	-1.0	0.9	0.7	0.4	0.4	1.2	0.9
PM-21	-0.4	-0.4	0.0	1.2	0.9	0.9	1.5	1.9	1.6
PM-22	0.4	0.3	0.7	-0.4	-0.3	-0.2	-1.2	-0.9	-0.9
PM-23	-0.6	-0.4	-1.5	-0.7	-0.6	-0.5	-0.3	-0.3	0.8
PM-24	0.1	0.9	-0.4	1.3	1.2	0.9	1.1	0.2	0.0
PM-25	1.1	0.9	1.2	1.1	1.2	0.0	-0.5	-0.9	-1.7
PM-26	-1.0	-0.7	-0.3	-1.5	-1.4	-1.0	-0.5	-0.2	0.2
PM-27	0.6	0.8	0.7	-0.5	-0.3	-0.3	0.6	-0.5	-0.5
PM-28	0.4	0.9	0.5	0.7	0.6	0.9	0.8	1.1	0.6
PM-29	0.8	0.5	0.5	-0.3	-0.1	0.7	1.1	0.6	1.2
PM-30	0.8	1.2	-0.1	-1.6	-1.3	-1.4	0.4	-0.5	1.5
PM-31	0.1	0.3	1.4	-0.6	-1.2	-2.2	-2.0	-1.8	-1.3

* Questions 8 & 9 are shown correctly with the opposite sign as they were originally calculated with in Table XX to correct for the error in ordering the responses from most positive to most negative rather than the typical method of from most negative to most positive (See Section XX for more details)

B.4 BP Rankings, Questions 4 to 9

Table XVIII: BP Ranking for Questions 4 through 9

Rank	Q4		Q5		Q6		Q7		Q8*		Q9*	
1	PM-10	1.8	PM-16	1.6	DC-2	1.3	PM-9	1.9	PM-17	2.0	PM-16	1.8
2	PM-16	1.7	PM-11	1.5	CM-1	1.2	PM-21	1.5	PM-16	1.9	PM-9	1.7
3	CM-4	1.3	CM-4	1.2	PM-1	1.2	PM-16	1.4	PM-21	1.9	PM-1	1.6
4	PM-24	1.3	PM-1	1.2	PM-2	1.0	PM-1	1.3	PM-6	1.6	PM-21	1.6
5	PM-21	1.2	PM-24	1.2	PM-9	1.0	DC-2	1.1	PM-1	1.5	PM-30	1.5
6	PM-25	1.1	PM-25	1.2	PM-14	1.0	PM-24	1.1	PM-2	1.2	PM-29	1.2
7	PM-1	1.0	FR-1	1.2	PM-16	0.9	PM-14	1.1	PM-20	1.2	PM-17	1.2
8	PM-20	0.9	PM-10	1.1	PM-21	0.9	FR-2	1.1	PM-28	1.1	PM-6	1.2
9	PM-9	0.9	PM-9	1.0	PM-28	0.9	PM-29	1.1	PM-9	0.9	PM-14	0.9
10	PM-14	0.8	CM-1	0.9	PM-11	0.9	PM-11	0.8	PM-12	0.8	PM-20	0.9
11	PM-2	0.8	PM-14	0.9	PM-24	0.9	PM-28	0.8	CM-4	0.7	PM-19	0.8
12	PM-6	0.7	PM-21	0.9	CM-4	0.7	CM-4	0.7	PM-4	0.7	DC-2	0.8
13	PM-28	0.7	PM-2	0.8	PM-29	0.7	FR-1	0.7	PM-29	0.6	PM-23	0.8
14	PM-11	0.7	PM-20	0.7	PM-6	0.7	CM-1	0.6	CM-3	0.4	CM-3	0.6
15	PM-17	0.7	FR-2	0.7	PM-8	0.7	DC-5	0.6	CM-5	0.3	PM-28	0.6
16	CM-1	0.6	PM-28	0.6	FR-1	0.6	PM-2	0.6	PM-24	0.2	DC-6	0.4
17	PM-4	0.5	PM-17	0.5	PM-17	0.5	PM-27	0.6	PM-8	0.2	PM-2	0.3
18	PM-5	0.4	DC-2	0.2	PM-4	0.5	PM-12	0.4	PM-19	0.1	CM-4	0.2
19	FR-2	0.3	CM-7	0.2	DC-5	0.5	PM-30	0.4	PM-3	0.1	PM-26	0.2
20	FR-1	0.2	PM-6	0.2	CM-7	0.4	PM-20	0.4	PM-15	0.0	PM-4	0.2
21	PM-8	0.2	DC-5	0.2	PM-20	0.4	PM-6	0.3	PM-18	0.0	FR-2	0.1
22	PM-12	0.1	PM-5	0.1	DC-1	0.3	CM-3	0.2	DC-2	-0.1	PM-12	0.1
23	DC-5	0.0	PM-8	0.0	FR-2	0.3	PM-17	0.1	DC-6	-0.1	PM-24	0.0
24	PM-15	0.0	PM-12	0.0	PM-5	0.1	PM-19	-0.1	FR-2	-0.1	PM-7	0.0
25	DC-2	-0.1	PM-29	-0.1	CM-3	0.1	CM-7	-0.1	PM-26	-0.2	CM-5	-0.2
26	DC-3	-0.1	PM-4	-0.2	PM-25	0.0	PM-4	-0.2	CM-7	-0.3	PM-11	-0.2
27	CM-3	-0.1	CM-5	-0.2	PM-10	-0.1	PM-8	-0.2	PM-23	-0.3	PM-18	-0.2
28	CM-7	-0.2	DC-3	-0.2	PM-19	-0.1	PM-23	-0.3	PM-14	-0.3	CM-1	-0.4
29	PM-3	-0.2	PM-27	-0.3	PM-12	-0.2	DC-1	-0.4	CM-2	-0.3	CM-2	-0.5
30	PM-29	-0.3	PM-22	-0.3	PM-22	-0.2	DC-3	-0.4	FR-1	-0.4	PM-27	-0.5
31	CM-5	-0.3	CM-3	-0.4	PM-27	-0.3	PM-25	-0.5	PM-5	-0.4	CM-7	-0.6
32	PM-22	-0.4	PM-15	-0.4	DC-3	-0.4	PM-26	-0.5	DC-5	-0.5	PM-5	-0.7
33	PM-27	-0.5	PM-7	-0.5	PM-23	-0.5	PM-7	-0.6	PM-27	-0.5	FR-1	-0.8
34	CM-2	-0.6	PM-23	-0.6	PM-15	-0.6	PM-5	-0.6	PM-30	-0.5	PM-8	-0.8

35	DC-1	-0.6	DC-6	-0.7	PM-3	-0.6	CM-5	-0.7	PM-11	-0.5	PM-22	-0.9
36	PM-31	-0.6	CM-2	-0.9	PM-7	-0.8	DC-4	-1.0	PM-25	-0.9	DC-5	-0.9
37	PM-23	-0.7	PM-19	-0.9	CM-5	-0.8	PM-3	-1.1	DC-1	-0.9	DC-4	-1.0
38	PM-7	-0.8	PM-3	-1.1	CM-2	-0.8	DC-6	-1.1	PM-22	-0.9	PM-15	-1.0
39	DC-6	-1.3	PM-31	-1.2	DC-6	-0.8	PM-15	-1.1	PM-10	-1.1	PM-10	-1.1
40	PM-19	-1.3	DC-1	-1.2	PM-26	-1.0	PM-22	-1.2	CM-1	-1.2	PM-3	-1.1
41	PM-26	-1.5	PM-30	-1.3	PM-13	-1.1	CM-2	-1.3	DC-3	-1.2	PM-31	-1.3
42	PM-30	-1.6	PM-26	-1.4	PM-30	-1.4	PM-10	-1.6	DC-4	-1.2	DC-1	-1.5
43	DC-4	-2.0	PM-13	-1.9	PM-31	-2.2	PM-13	-1.7	PM-7	-1.3	PM-13	-1.6
44	PM-13	-2.1	DC-4	-2.1	DC-4	-2.7	PM-31	-2.0	PM-31	-1.8	PM-25	-1.7
45	PM-18	-2.4	PM-18	-2.3	PM-18	-2.9	PM-18	-2.2	PM-13	-2.5	DC-3	-1.9

B.5 Top Ranked Best Practice Descriptions (Source CMSC)

CM-4 Conduct Weekly Issues Meeting

Description:

Implement weekly internal WisDOT project management team issue meetings to discuss status of project, scope, cost, schedule, and review any issues. Attendees for these meetings should include the construction project leader, DOT or local project manager, and as needed, the DOT or local project supervisor, and key construction team members. The weekly issue meeting should review the Issues tracking log to review/discuss/update the issues list for the project. The results from the weekly issue meeting should be reported to the Region Change Management team.

Additional Details:

Issues that should be considered for discussion at the weekly meeting are those that:

- Have the potential to generate significant negative press
- Have the potential to create negative external stakeholder impacts
- Have the potential to significantly impact major traffic patterns
- Are commitments made by the administration or that the administration has expressed interest in
- Are clearly risk issues for the Region/Bureau, Division, Department
- May set a precedent or change Departmental policies or procedures
- May exceed your resources to resolve issue
- Will challenge the project (legislative, political, business relationships, funding, community/public, outreach)

Objective:

Primary: Issue Management

Secondary: Schedule Control, Cost Control, Communication

When to Apply:

Best practice should be applied on the large, complex mega projects.

Cost Implications:

This practice will result in fairly low cost impacts. It may require additional manpower as it requires attendance at another meeting for project staff.

Conditions for Successful Application:

This best practice requires project leadership to support and attend this meeting. Often the items and topics will be discussed at other project meetings and this meeting can seem redundant if the importance of being able to discuss issues internally is not reinforced. Meetings should be regularly scheduled standing meetings. Meeting frequency (weekly or bi-weekly) depends upon project complexity.

Cautions:

To be effective requires the project delivery team to be functioning well as a team with participants being open and willing to share problems.

PM-1 Employ a defined hierarchy for decision making

Description:

Use a pre-defined hierarchy for decision making to promote timely project decision making and foster decision making at the lowest responsible level. The decision making hierarchy should have well-defined dollar thresholds based upon the authority level.

Additional Details:

Higher cost and higher risk decisions are placed in the hands of more experienced staff. Also, having the hierarchy clearly defined within the department ensures that all team members stay within their prescribed bounds. Suggested approval levels and time frames based upon past mega and American Recovery and Reinvestment Act (ARRA) projects are shown in the following table:

CONSTRUCTION CONTRACT APPROVALS

	Project Leader	Project Manager	Supervisor	Chief
Contract Mod Increase/Decrease	≤ $25,000	≤ $100,000	≤ $250,000	≤ $500,000
Timeframe for Decision	1-2 days	2 days	2 days	5 days

Objective:

Primary: Issue Management

Secondary: Schedule Control, Cost Control, Communication

When to Apply:

Best practice should be applied on all projects.

Cost Implications:

This practice will result in minimal cost impact.

Conditions for Successful Application:

This best practice requires that project level staff be given sufficient training on contract administration and upper levels of management are willing to trust lower levels to make correct decisions. The decision hierarchy should be presented at the project preconstruction meeting and agreement obtained between the contractor and project management staff regarding timeframes for making decisions.

Cautions:

Occasionally mistakes will occur, which could potentially result in added costs to the project. However, these must be accepted and then used as an opportunity to educate staff on the proper decision to be made.

PM-2 Use a Request for Information (RFI) form and process

Description:

A Request for Information (RFI) form should be used by the prime contractor to obtain clarification of the plans, specifications, special provisions, or other contract documents for themselves or for their subcontractors. It provides a means to document and monitor questions that arise during construction, the answers provided, and the timing of the response. Use of an RFI form provides more structure to the issue identification process, more accountability for providing answers or decisions to questions, and a more formal documentation process for the issues identified. The RFI process should include a RFI Log to track the status of submitted RFIs.

Additional Details:

A Request for Information (RFI) form has standard entry spaces to allow the submitter to enter:

a) Date of submittal
b) Name of submitter
c) Division code or reason code
d) Information requested (a concise question with reasoning as to importance)
e) Date answer is required
f) Priority level of the issue (high, medium or low)
g) Unique tracking number

And the responder to enter:

h) Date the response is provided
i) Response (a concise answer to the question)
j) Name of the responder
k) Reason Code

Objective:

Primary: Schedule Control
Secondary: Issue Management, Dispute Resolution, Communication

When to Apply:

Best practice should be applied on all mega projects, backbone and 3R projects with construction costs in excess of $1 million.

Cost Implications:

This practice may result in significant costs if commercial software is used for RFI processing and tracking. Costs will be minimal if a simple Excel spreadsheet or Word document is used for submittals and tracking is done manually.

Conditions for Successful Application:

Metrics such as the number of RFIs per million dollars of contract work and average response times should be monitored. It is recommended practice that all sub-contractors submit RFIs to the prime contractor and the prime contractor screens the RFI before submittal to the DOT. RFI Logs should be shared and reviewed with the prime contractor frequently, possibly at the weekly project progress meetings. The joint RFI Log review results in discussions about specific RFI's, the timeline for a response and can help determine a priority. Management needs to make all effort to respond to RFI within the requested period. In successful projects 66 percent of RFIs were answered within the requested time period.

Construction contractors generally support use of an RFI system and voluntarily agree to use of the forms.

Cautions:

The RFI process can be abused by some contractors to establish a claim against DOT for slow response to RFI's or by submitting a high number of RFIs. The project leader and prime contractor should agree on the types of issues that will warrant submittals of RFI's prior to starting construction.

PM-6 Require Use of Three-Week Look-Ahead Schedules

Description:

Require the contractor to weekly submit a three-week look-ahead schedule that includes the following:

1. Activities underway and as-built dates for the past week
2. Planned work for the upcoming two-week period
3. Potential impacts to traffic patterns, planned community activities, noise issues or other environmental aspects for upcoming two-week period

On a weekly basis, the department and the contractor agree on the as-built dates depicted in the three-week look-ahead schedule or resolve disagreements.

Additional Details:

The contractor is responsible for preparing and presenting the three-week, look-ahead schedule at weekly project meetings. Specific items that can be addressed in a look-ahead schedule include lane and ramp closures, current work activities, critical submittals/reviews, critical procurements, noise impacts, equipment needs, potential delays and other problems.

Objective:

Primary: Schedule Control
Secondary: Issue Management, Dispute Resolution, Communication

When to Apply:

Best practice should be applied on mega projects, backbone and large to medium 3R projects.

Cost Implications:

This practice should result in minimal cost increases.

Conditions for Successful Application:

This best practice requires special provisions requiring the contractor to submit three-week look-ahead schedules and involvement of project management staff to critically review the submitted schedules and make discussions with the contractor a priority.

Cautions:

This practice requires the contractor to submit an accurate and comprehensive construction schedule at the beginning of the project and willingness to devote the time to developing and updating the three-week look-ahead schedules. This process can be used with a variety of scheduling tools such as CPM, Linear Schedules, Relationship Bar Charts, or Bar Charts.

PM-9 Establish project Close-Out Procedures early in project and track progress

Description:

Establish project close-out procedures with the contractor early in the construction phase of the project. Develop an agreed upon process for partial acceptance leading to final acceptance. Require the contractor to submit a schedule for completion of punch-list items. Conduct periodic review of preliminary finals to expedite final closeout items. Identify close-out items that can be worked on simultaneously or in parallel acceptance. Track closeout progress and assign action items as needed.

Additional Details:

Reviews of the finals progress/milestones should be done monthly until the process is essentially complete then quarterly until the project is closed. Expedited close-out procedures allow project staff to be assigned to other projects sooner and result in unspent project funds being released to other projects for better program management.

Objective:

Primary: Schedule Control

Secondary: Issue Management

When to Apply:

Best practice should be applied on mega projects, backbone and large 3R projects or any project where traffic impacts economic activities.

Cost Implications:

This practice will result in no significant cost implication.

Conditions for Successful Application:

While the standard specifications define substantially complete, each project's unique circumstances and criteria should be discussed and agreed upon early in the project.

Cautions:

Poor definitions of project completion must be taken into account to prevent increased costs and time.

PM-16 Assign a responsible party for resolution of issues at Project Progress Meetings

Description:

Weekly project progress meetings are conducted to: A) review construction progress and future work activities, identify potential delays as early as possible for mitigation planning, raise issues and bring them to resolution, and B) make subsequent action assignments when appropriate. Those given action assignments should be identified (referred to as “Ball in Court”) in the meeting notes and assigned a date when resolution is due. The identified responsible party should be a person who is directly on the project and answers to the project team so that that person’s work priorities are set by the team and will not be overridden by others.

Additional Details:

A standardized meeting note format should be followed to insure all issues brought up are documented, a responsible party is assigned for resolution of the issue, and the issue is brought to resolution.

Objective:

Primary: Issue Management

Secondary: Schedule Control, Communication

When to Apply:

Best practice should be applied to all mega, backbone and all 3R projects where construction project progress meetings are held.

Cost Implications:

This practice will result in minimal costs to implement. While use of standardized forms may be helpful, application does not require that the information be captured in any prescribed format.

Conditions for Successful Application:

Top management will need to reinforce the use of this best practice on projects for early resolution of any potential issues. Support from construction contractor's personnel on use of the best practice at the project level will enhance the likelihood of success.

Cautions:

None

PM-17 Make "Open Issues" a routine agenda item at Project Progress Meetings

Description:

Weekly project progress meetings are conducted to: review construction progress and future work activities, identify potential delays as early as possible for mitigation planning, raise issues and bring them to resolution, and make subsequent action assignments when appropriate. All issues identified should be assigned a unique number, date it was brought up, a brief description of the item, status of the item (new, open, closed or for discussion), who is responsible for taking the lead in resolving the item, and when the resolution is due. All items are carried forward as "open" until meeting participants agree that resolution has been reached and the item can be closed. At each meeting, all "open issues" should be a standing item and have the responsible party report on the progress and the status.

Additional Details:

A standardized meeting note format should be followed to ensure all issues brought up are documented as well as the resolution of the issue is achieved in a timely manner.

Objective:

Primary: Issue Management

Secondary: Cost Control, Schedule Control, Communication

When to Apply:

Best practice should be applied on all mega projects and most 3R type projects. Shorter duration, straight forward type 3R projects would benefit from utilizing the concept but may not warrant utilizing the more complex proprietary document control and reporting software available.

Cost Implications:

This practice will result in low cost impacts.

Conditions for Successful Application:

Mega projects should utilize commercial software to allow electronic filing, tracking and search capabilities. Other projects could utilize standardized word processing templates as provided in the Project Communications Enhancement Effort (PCEE) Manual.

Cautions:

None

PM-20 Hold Specialty Group Meetings

Description:

Project Specialty Group meetings should be held to improve communication among those involved with specific aspects of the work. It should include project personnel, contractors, outside agencies, WisDOT offices, municipalities, and other third-party groups as needed that are involved in the specific specialty area. Meetings should cover: construction progress, future work activities, potential delays for mitigation planning, possible impacts to traffic or community events, issues that need resolution, and make action assignments when appropriate.

Additional Details:

Utility coordination, traffic operations, structures group, DBE compliance, etc. are examples of the specialty group meetings that should be held. These meetings are focused on a specific functional area and resolving issues related to that aspect of the project. They are separate meetings and NOT part of normal Project Progress meetings or Partnering meetings.

Objective:

Primary: Schedule Control

Secondary: Issue Management, Communication, Cost Control

When to Apply:

Best practice should be applied on large, complex mega projects.

Cost Implications:

This practice will result in slight increases to cost.

Conditions for Successful Application:

Senior management must support the attendance of project staff and regional/statewide bureau functional area staff at the meetings. Often third parties, such as utility companies, county sheriffs, state patrol, municipalities, etc. will be required to attend and obtaining their commitment to the meeting is important. Meetings should be regularly scheduled, standing meetings organized and led by the construction project delivery staff.

Cautions:

None

PM-21 Use Work Authorization Form (WAF)

Description:

Prior to receiving an Approval Justification Record (AJR), a Work Authorization Form (WAF) is used to direct and start contract modification work by the contractor. The WAF provides the contractor with a written document detailing the work to be performed and the basis of payment in advance of completion of the Contract Modification process.

Additional Details:

The WAF can also be used to document how the project team proposes to address a change and request the contractor to respond officially that the proposed action, payment method and time consequences are acceptable to them.

Objective:

Primary: Communication

Secondary: Cost Control, Schedule Control, Issue Management, Dispute Resolution, Document Control

When to Apply:

Best practice should be applied on mega projects, backbone and large to medium 3R projects. Consider standardizing this practice and using on all projects.

Cost Implications:

This practice will result in minimal cost increases.

Conditions for Successful Application:

This best practice requires development of a standardized form and the project management team being able to accurately define and detail the work to be done by the contractor. Payment and time considerations are typically agreed upon through negotiation prior to issuing the WAF.

Cautions:

If there is a disagreement regarding acceptance of the payment or time provisions detailed in the WAF, they need to be resolved promptly through negotiation or use of the pre-established dispute resolution process.

PM-28 Encourage Third- Party representation at Project Progress Meetings

Description:

Encourage third-party representatives to attend project progress meetings to facilitate dialog between the parties, clarify expectations, and acquire agreements on actions and target dates for completion. Examples of third parties would be utility companies, local units of government, local law enforcement agencies, external agencies such as the DNR, and railroads.

Additional Details:

This best practice can be used in conjunction with PM-20 (hold Specialty Group meetings) if project complexities require it, but it should be applied if PM-20 is not utilized.

Objective:

Primary: Communication

Secondary: Schedule Control, Issue Management

When to Apply:

Best practice should be applied on all projects.

Cost Implications:

This practice will result in minimal cost impacts.

Conditions for Successful Application:

Meeting logistics are important and scheduling meetings to allow participation should be explored. This may include establishing teleconference lines or making web-based meeting participation possible.

Cautions:

Third-party participants may seek compensation for attendance and expectations regarding attendance need to be clarified up-front. Pressure may need to be exerted on third parties to ensure participation in relevant communication activities. Conversely, some third party participants can be disruptive to the process and caution needs to be exercised to ensure their involvement is controlled.

PM-29 Establish project goals for timely approval of documents

Description:

Establish project team goals for responding to and turning around project documents and submittals, e.g. responding to all RFIs in seven days. These are non-binding, turn-around dates, but it provides contractors with an approximate time frame for when they can expect responses as well as gives the project team a goal response time to strive for to prevent documents from lingering without a response.

Additional Details:

Types of documents where response time goals could be established include RFI's, Shop Drawing Reviews, Materials Submittals, Correspondence, etc. Different response time goals can be established for each type of document or submittal. Time goals should be developed collaboratively with contractor.

Objective:

Primary: Schedule Control

Secondary: Issue Management, Communication

When to Apply:

Best practice should be applied to all projects.

Cost Implications:

This practice will result in minimal cost impacts.

Conditions for Successful Application:

Project delivery staff must make realistic estimates of their expected response time based upon staffing levels and anticipated frequency and volume of submittals and documents. Then staff must make it a priority to meet or exceed these goals. Periodically the project team should measure performance and seek improvements if necessary.

Cautions:

It is possible that contractors may misuse requested turn-around time goals by demanding rapid response to all issues. Discussions should be held at the pre-construction meetings to establish criteria for urgent response items.

APPENDIX C

C.1 WisDOT Project Class Codes

CODE VALUE	CODE DESCRIPTION
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A	GENERAL CONSTRUCTION
AB	GENERAL CONSTRUCTION AND GRADING
ABC	GEN CONST AND PCC PAVEMENT AND GRADING
ABD	GEN CONST AND GRADING AND ASPH SURFACE
ABF	GEN CONST AND GRADING AND STRUCTURES
ABK	GEN CONST AND GRADING AND INCIDENTAL
AC	GENERAL CONSTRUCTION AND PCC PAVEMENT
ACD	GEN CONST AND PCC PVMT AND ASPH SURFACE
ACF	GENCONSTANDPCCPVMTANDSTRUCTURES
ACK	GEN CONST AND PCC PVMT AND INCIDENTAL
AD	GENERAL CONST AND ASPHALTIC SURFACING
ADE	GEN CONST ASPH SURF GRAVEL OR CR STONE
ADF	GEN CONST AND ASPH SURF AND STRUCTURES
ADK	GEN CONST AND ASPH SURF AND INCIDENTAL
AE	GEN CONST AND GRAVEL OR CRUSHED STONE
AF	GENERAL CONST AND HIGHWAY STRUCTURES
AFH	GENCONSTANDSTRUCTANDBRIDGEPAINTING
AFK	GENERAL AND STRUCT AND INCIDENTAL CONST
AG	GENERAL CONSTRUCTION AND RAILROAD
AH	GENERAL CONSTRUCTION AND BRIDGE PAINTING
AJ	GENERAL AND BUILDING CONSTRUCTION
AJK	GEN CONST AND BUILDING AND INCINDENTAL
AK	GENERAL AND INCIDENTAL CONSTRUCTION
B	GRADING
C	PORTLAND CEMENT CONCRETE PAVEMENT
CFK	PCC PVMT AND STRUCT AND INCIDENTAL CONST
CK	PCC PAVEMENT AND INCIDENTAL CONSTRUCTION
D	ASPHALTIC SURFACING
DE	ASPHALTSURFACEANDGRAVEL/CRUSHEDSTONE
DK	ASPHALTIC SURFACING AND INCIDENTAL CONST
E	GRAVEL OR CRUSHED STONE
F	HIGHWAY STRUCTURES
FH	HIGHWAY STRUCTURES AND BRIDGE PAINTING
FK	HIGHWAY STRUCTURES AND INCIDENTAL CONST
G	RAILROAD ROAD AND BRIDGE
H	BRIDGE PAINTING
I	STREET AND AIRPORT LIGHTING
IK	STREET N AIRPORT LIGHTING N INCIDENTAL
J	BUILDING CONSTRUCTION
JK	BUILDING AND INCIDENTAL CONSTRUCTION
K	INCIDENTAL CONSTRUCTION
NONL	NON LET PROJECT

Figure 34: List of the 42 class codes used by the WisDOT (Source WisDOT)

C.2 ANOVA results of regression model analysis for a single project

Table XIX: ANOVA results comparing regression models on a single project

Model 1: Cost ~ 0 + Time						
Model 2: Cost ~ 0 + Time + I(Time^2)						
Model 3: Cost ~ 0 + Time + I(Time^2) + I(Time^3)						
Model 4: Cost ~ 0 + Time + I(Time^2) + I(Time^3) + I(Time^4)						
	Res.Df	RSS	Df	Sum of Sq	F	Pr(>F)
1	12	0.097646				
2	11	0.071862	1	0.025784	31.0971	0.0003445 ***

	Res.Df	RSS	Df	Sum of Sq	F	Pr(>F)	
3	10	0.012504	1	0.059358	71.5889	1.411e-05	***
4	9	0.007462	1	0.005041	6.0803	0.0358150	*

C.3 ANOVA results comparing regression models for all 20 projects

Table XX: ANOVA results comparing regression models for all 20 projects

Analysis of Variance Table
Model 1: Cost ~ 0 + Time
Model 2: Cost ~ 0 + Time + I(Time^2)
Model 3: Cost ~ 0 + Time + I(Time^2) + I(Time^3)
Model 4: Cost ~ 0 + Time + I(Time^2) + I(Time^3) + I(Time^4)

	Res.Df	RSS	Df	Sum of Sq	F	Pr(>F)	
1	265	4.8874					
2	264	4.5818	1	0.305622	17.8341	3.328e-05	***
3	263	4.5803	1	0.001496	0.0873	0.76790	
4	262	4.4899	1	0.090416	5.2761	0.02241	*

C.4 Best fit regression model analysis

Table XXI: Best fit model parameters

Call:
lm(formula = Cost ~ 0 + Time + I(Time^2), data = best)
Residuals:

Min	1Q	Median	3Q	Max
-0.38718	-0.07864	0.00000	0.06034	0.48802

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
Time	1.29043	0.06227	20.724	< 2e-16	***
I(Time^2)	-0.30869	0.07356	-4.196	3.71e-05	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.1317 on 264 degrees of freedom
Multiple R-squared: 0.9631, Adjusted R-squared: 0.9628
F-statistic: 3446 on 2 and 264 DF, p-value: < 2.2e-16

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