Application of Lean Construction Principles to Highway Projects:

Analysis of Barriers to Timely Delivery of Service

A Thesis

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by

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Dedications

This work and all that follows are dedicated to my parents, Bob and Adele Muir. I appreciate and value all of the many lessons you taught, the attitudes you imparted, but most especially your love and unselfish devotion. Dad, the work ethic and sense of responsibility that you instilled in your children underpins whom your children are today. Although my mother passed away in August 2001, her influence continues to guide and direct my footsteps each day. I love you both very much!

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This completion of this challenging work and the achievement of a PhD is proof of the scripture found in Romans 8:28 paraphrased “it will all work out.”

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Abstract

Application of Lean Construction Principles to Highway Projects:

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Highway project delivery of new and reconstructed facilities in the United States is viewed to consume too much time, thereby denying the traveling public of urgently needed infrastructure. The purpose of this thesis is to gain a better understanding of current highway project delivery and suggest interventions intended to enhance time performance. The major research focus is the Highway Project Performance (HPP) Study. The HPP study examined empirical data collected from 65 projects completed by 10 public highway agencies in the Northeast and Mid-Atlantic regions of the United States. Research included determining frequency and magnitude of duration escalation and identifying the input variables of process, practices, conditions, and constraints under which typical highway projects are delivered.

Non-parametric procedures were used to test for differences among participating highway agencies. The Kruskal-Wallis and Mann-Whitney tests were employed to evaluate differences in mean TPI values for late and on time project subsets. Chi-square tests were conducted to analyze the difference in observations between the combined multi-dimensioned categories. Odds Ratio (OR) and relative risk or the risk ratio (RR) values were computed for the various categories including process and practices.

Logistic regression was applied to the constraints as an additional test procedure. Semantic response differentials for each of the key performance indicators were also evaluated.

The HPP Study findings showed that approximately 66% of highway projects finish beyond the original contract duration with a mean Time Performance Index (TPI) of 0.859. Projects exposed to phased maintenance of traffic (MOT), utilities, streams or waterways, and railroads exhibit the greatest relative risk for duration escalation. Primary arterials, projects that combine bridge and roadwork, and those located in urban environments also exhibit greater relative risk of duration escalation. The relative risk of duration escalation increases exponentially with increase of project cost. Late and On Time project subsets exhibit differences in mean semantic differentials (MSD values) in constructability, the degree to which contract documents address constraints, quality and effectiveness of the contractor's schedule, and trust between the contractor and owner. These findings provide focus and motivation for owners to reduce the risk of duration escalation.

CHAPTER 1: INTRODUCTION

1.1 Overview

The following thesis titled Application of Lean Construction Principles to Highway Projects: Analysis of Barriers to Timely Delivery of Service was prepared by Robert Wm. Muir, Jr., PE in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Civil Engineering, under the direction of Joseph P. Martin, Ph.D., PE, Department of Civil, Architectural, and Environmental Engineering (CAEE) at Drexel. The work was also guided and assessed by the full Ph.D. Advisory Committee including Dr. Patrick Gurian and Dr. Shi-Chieh Cheng, both from the CAEE at Drexel and Dr. Hazem Maragah, Decision Sciences, LeBow College of Business, Drexel University. Dr. Anthony Songer, Boise State University, is an external member of the committee.

The purpose of this research was to gain a better understanding of the current state of highway project delivery and suggest interventions intended to enhance time performance. There are two objectives of this study. The first set of objectives is to assess the time performance of highway projects and to identify the input variables such as the processes, conditions, and constraints under which the individual projects were delivered. The thesis examines the relationships between explanatory input variables and the dependent outcome variables in order to gain a deeper understanding of time performance and duration escalation on highway construction projects. The second objective is to propose interventions to reduce the time component and improve reliability of highway project delivery and suggest the necessary implementation strategies.

1.2 Background and Significance

The United States faces an infrastructure crisis in which deteriorating bridges and highway congestion threaten the economic prosperity and quality of life associated with travel mobility. The Nation's road system received a grade of "D-" from the American Society of Civil Engineers (ASCE) on the organization's Infrastructure Report Card 2009 (ASCE 2009). Currently, highway project delivery of new and reconstructed facilities is viewed to consume too much time, thereby effectively denying the traveling public of urgently needed infrastructure. Exacerbating this situation are the funding shortfalls plaguing most highway agencies. Extended project delivery time and the resulting negative impact on the traveling public and the community at-large is a growing major concern. The taxpaying public grows increasingly frustrated by the poor time performance of highway construction projects (Sillars 2009). While protracted construction durations cause state and local Departments of Transportation (DOTs) to incur extended internal and external overhead costs, the greater financial burden is borne by commercial carriers and the traveling public in general. These costs include the delayed relief of congestion and increased travel time. Environmental and safety concerns include emissions, maintaining traffic through hazardous work zones, and risks associated with temporary structures such as sheeting, shoring, plated trenches, and falsework. Other safety concerns include emergency vehicle access and the amplified travel time for emergency responders. Transportation professionals are called upon to do more with less in half the time. The current situation poses the question how can highway projects be delivered quicker yet more economically without sacrificing quality?

Research to date includes investigation of potential acceleration techniques or approaches to ensure timely delivery (Sillars 2009). Research conducted under request by AASHTO (American Association of State Highway and Transportation Officials) identified twenty-eight good practices that stronger performers applied to enhance schedule performance. However, the best performers still completed 27% of their projects beyond the original contract duration and 42% were completed beyond the original time frame for contracts over $5,000,000. A pilot test conducted in preparation for this proposed study revealed a mean Time Variance (TV or Δt) of 65% beyond original contract duration and a mean Time Performance Index (TPI) of 0.67. A reliable statistical inference cannot be made to the population mean for cost and time, given the small sample size limited to seven (7) projects. Nevertheless, the information garnered indicates performance problems that demand further investigation.

Recent research has sought to improve the accuracy and reliability of estimated activity durations for highway agencies. (Williams 2009). Some states have incorporated a tracking system with a feedback loop to identify causes of delays. Causes of delays can often be traced back to preconstruction and the feedback loop is intended to provide lessons learned that serve as a guide in avoiding future delays (NCHRP 2007). However, there is currently no dissemination of these lessons beyond individual agencies.

Forensic schedule analysis (FSA) is often employed in practice to address delays and disruption for claims and litigation, but there has been very little formal scholarly research to determine the range and magnitude of project duration escalation. While the source of time growth and other factors that impact duration are tacitly known, their direct relationships have not been quantified, nor have true systemic issues been addressed. Nor has there been extensive scholarly work to examine the nature and root causes of delays in highway construction or to quantify correlations between project variables and time growth. The work in this study included quantifying project duration escalation on highway construction projects. The work also sought to identify correlations between input variables related to the processes, conditions, and constraints under which the individual projects were delivered. The work attempted to identify and quantify correlations between the explanatory input variables and the dependent outcome variables in order to gain a deeper understanding of duration escalation on highway construction projects and propose new interventions.

Research to date has identified various strategies and practices to avoid delays and potentially accelerate delivery of highway projects. Some of these address utility conflicts and relocations, geotechnical investigation, constructability studies, permits and right-of-way acquisition, and prequalification of contractors. These interventions are sound, and if implemented, could contribute towards improving time performance. However, preliminary results of a pilot study conducted for this work along with interviews with subject matter experts (SMEs) and literature review indicates that many factors affect time performance and contribute towards project duration escalation. These factors include quality and completeness of contract documents, physical constraints beyond utilities and subsurface conditions, level of trust and cooperation between the SHA and contractor, adequacy of SHA and contractor project administration, and project complexity.

1.3 Literature Review

The current literature was reviewed in preparation for this study and provides the necessary conceptual framework. The sources include journal articles, conference proceedings, technical reports, and textbooks on the subjects of transportation engineering, project management, construction engineering and management, operations management, organizational behavior, and industrial engineering. Specific topics include construction planning and scheduling; highway planning, design, and construction; Lean production, Lean construction, and Lean project delivery; constructability concepts and analysis; risk management in project development and construction; and others. Literature review continued through the final stages of this study.

A strong case for the need to reduce the delivery time of highway projects is found in the literature going back to 1975 (NCHRP 1975). Suggestions for research into dramatically reducing highway construction times were published in a report by the FHWA (Federal Highway Administration) Research and Technology Coordinating Committee in 1998 (FHWA 1998, O'Connor 1998). A series of three workshops were conducted under the co-sponsorship of the Transportation Research Board's (TRB) Task Force on Acceleration Innovation in the Highway Industry, AASHTO, and FHWA. The first was held in Washington, DC in November 2000, the second in Indianapolis, IN in March 2002, and in Pittsburgh, PA in April 2002 (AASHTO 2003). The discussions at that time centered on negative impacts associated with protracted construction project durations and the affected elements. The workshops provided the impetuous to search for and test innovative approaches to accelerating construction.

Since that time, workshops of the same theme have been held across the country with various levels of documentation and dissemination of lessons. The message was intensified in the AASHTO publication titled Accelerating project delivery: It's about time. That particular publication along with several others examines innovative methods of acceleration project delivery (AASHTO 2006). Numerous other examples of “silver bullet” solutions are found in the literature. Such solutions include incentive/disincentive clauses, lane rental, A+B procurement, and various alternative project delivery methods.

A report prepared for the National Cooperative Highway Research Program (NCHRP) in 2001 proposed 40 recommendations to improve time performance and avoid delays (Thomas and Ellis 2001). Those initial ideas were further refined and presented with implementation details (Thomas, Ellis, and Sinha 2006). The recommendations were more holistic in nature and included establishing criteria to identify time-sensitive projects, best practices for avoiding utility relocation, and suggesting stronger formalized qualifications criteria for contractors. The work also included further discussions on A+B contracting. A synthesis of highway practice prepared for the NCHRP discussed Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion. The work serves a guidebook for DOTs in selecting and employing alternative contracting methods (ACM). These include design-build, incentive/disincentive contract clauses, cost-plus-time biding, interim completion dates, and no-excuse incentives (Anderson and Damnjanovic 2008).

Other literature has focused on improving prediction of time performance. Some of the early work to formalize forecasting of project duration for construction contracts was performed for the Florida Department of Transportation (Shapanka and Allen 1984). The early methods attempted to predict project duration by correlating original contract value, project type, and road system to time. An NCHRP study investigated the methods used by various DOTs to establish contract duration for highway projects (Herbsman and Ellis 1995). The study found that many states used manual methods incorporating a predefined set controlling activities, logic, and production rates. The study showed that some used CPM calculations. The report noted the importance of including certain factors such as utility work, geotechnical conditions, project characteristics and legal considerations. The report concluded with the recommendation of developing a statistical database to support project duration predictions and employing expert systems to support engineering judgment.

In 2000, the Kentucky Transportation Cabinet (KyTC) employed a consultant team to develop six predefined project templates for use as tools for predicting project duration (Hancher and Werkmeister 2000). The templates were developed with input from the KyTC in terms of expected ranges of production rates. The KyTC system utilizes Microsoft Project as its platform. Similar templates were produced for the South Carolina Department of Transportation (SCDOT) based on work types and production rates (Stoll et al 2006). The SCDOT system uses Primavera Project Planner (P3) as its platform.

The Washington State Department of Transportation (WSDOT) engaged a consultant for a more in depth study of performance analysis and forecasting for highway projects (Abdel 2007). This study not only examined current practices, but it also evaluated time growth of construction projects. The study revealed that 53.3% of all WSDOT projects finished beyond their original planned (contract) dates, with a mean time growth of 21%. The WSDOT research also included an analysis of time growth against main project variables. However, these “main variables” include quantities (tons) of hotmix asphalt (HMA) and length of project in terms of mileage. While this information may be useful in more accurate duration predictions, they do not identify causes for the delay and neglect other controlling variables.

1.4 The Lean Paradigm

Lean Production Theory was born in the manufacturing sector, specifically in the Japanese auto industry after World War II. The concepts were pioneered by Taiichi Ohno, a Toyota Motor Company engineer and executive as a means of gaining competitive advantage through eliminating waste and delivering consistently high quality products (Diekmann et al, 2004). The result was a fundamental shift from mass production to Lean production that placed the company at the front of the auto industry (Womack et al, 1990). Lean Production is often referred to as the Toyota Production

System (TPS) and is believed to be the best modern production system (Womack and Jones, 1996).

Lean Production is touted as "Lean" since it consumes less of all of the resources typically associated with mass production. Some claim that Lean production requires half the human effort, half of the manufacturing space, half the investment in tools, and half the engineering hours to develop a new product. It is further claimed that Lean production requires less than half the inventory, results in fewer defects, and is capable of producing an expanded array of products (Womack et al, 1990). This thesis however does not rely on Lean manufacturing principles but on Lean Construction theory and Lean Project Delivery concepts developed and articulated since the early 1990's by Koskela, Ballard, Howell, Bertelsen, and others within the International Group for Lean Construction (IGLC) (Howell, 1999, Howell and Ballard, 1999, Howell and Koskela, 2000, Ballard and Howell, 2003, Bertelsen 2004, Pheng and Fang, 2005, Alves and Tsao, 2007, Bertelsen and Sacks, 2007). Ultimately, this effort sought to identify a new paradigm, which transcends systems and processes to affect the culture of highway agencies. Proposed interventions to enhance project performance are derived from approaches elucidated in the current literature.

1.5 The Value of Time

Time is a growing concern for users of transportation infrastructure in the United States. The traveling public faces extended commutes and lengthened trip durations as a result of congested or otherwise inadequate transportation networks (FHWA, 1998). Construction and reconstruction of transportation facilities, specifically highways, is viewed to consume too much time. There is a quantifiable cost of low levels of service (LOS). It can be stated that time is value to the traveling public. Highway projects often exceed the allotted contract time with negative impacts to the traveling public and society at-large. Highway contract documents typically require that contractors employ prevailing time management methodologies such as Critical Path Method (CPM) of scheduling, yet escalation of original project duration is common. In this thesis, time is viewed in a sense from both micro and macro perspectives. The micro view is of travel time for individual travelers, while the macro view considers the time in which the traveling public is denied adequate facilities. The latter includes the time before physical improvements begin as well as the construction duration required to complete the improvements. The total impact to the traveling public is the product of the two; i.e. extended daily travel time multiplied by the number of days in which travel time is impacted. Once a project is deemed necessary, delaying the delivery of the required infrastructure means extended inconvenience to the traveling public. Furthermore, highway construction often disrupts traffic flow and increases travel time.

The American Association of State Highway and Transportation Officials (AASHTO) has identified the protracted duration of project delivery of highway projects as primary target for improvement and has issued the challenge that “The Federal Government should set a goal of cutting the current project delivery time in half, achieving in five to seven years what now takes 10 to 15” (AASHTO, 2007). Regarding the construction phase, AASHTO Past President and former New Jersey Department of Transportation Commissioner Jack Lettiere stated that “We have to challenge our contractors to use all their creativity to deliver their work both faster and at the same quality standards we require" (AASHTO, 2005). Accelerating the delivery of transportation projects has become a priority for State and local DOTs and the focus of much research and recommended change initiatives. The highway industry clearly has a mandate to accelerate project delivery without sacrificing quality or safety.

Yet in spite of this mandate, poor schedule performance of highway construction is an on-going concern. Research conducted under request from AASHTO identified twenty eight good practices that stronger performers applied to enhance schedule performance. However, the best performers still completed 27% of their projects beyond the original contract duration and 42% were completed beyond the original time frame for contracts over $5,000,000. The extended duration of highway project delivery effectively extends travel time.

While time has no direct intrinsic monetary worth, it has imputed monetary worth. There are undeniable monetary costs associated with hindering the free flow of goods and services, and the traveling public at-large (Sinha and Labi, 2007). Transportation economics considers the value of time as the opportunity cost of the time, which a traveler spends on a trip whether for work or non-work related travel. The Value of Travel Time Savings (VTTS) is a subject of ongoing research for which there are empirical data and various models available to transportation planners and designers. The time value of money is well understood. Time preference is less understood but generally accepted as a quantifiable value (Frederick et al, 2002). Time preference generally refers to the value of immediate utility over delayed utility, a theory, which underpins many VTTS models (Mackie et al, 2003).

A practical way in which VTTS is considered in design and during construction is in road user costs (RUC). RUC is the estimated daily cost to the traveling public resulting from travel delays or disruptions attributable to construction (Daniels et al, 1999). RUC is also the relative cost of denying the traveling public of the intended benefits of the project, i.e. reduced trip times (Zhu et al, 2009). RUC is a value that is calculated typically as a basis for contractual arrangements. These include setting values for incentive/disincentive clauses for early completion, penalties for disrupting peak traffic flow, and for the "B" component of A+B contracting. The "B" component in this context is the contractor's proposed construction duration multiplied by a daily RUC amount specified in the contract proposal. The "A" component is the estimated cost of construction including markups for overhead and profit.

Time should be treated as a resource. Though time is not a physical, tangible resource it is a virtual resource nonetheless. This supposition is based on the fact that: 1) time can be quantified and consumed, 2) it is an input or at least a condition required for an action or task to be executed, 3) requires some level of management effort for production. Resources have value.

Basic tenets of Lean thinking include identifying and eliminating waste; identifying and delivering value to the customer and eliminating anything that does not add value; establishing production as a continuous, reliable flow; and pursuing perfection through continuous improvement. Lean is value–centered; value as defined by the customer. Who are the customers? The DOTs serve as surrogate owners and are the initiators and administrators of highway projects. As such, the DOTs are merely caretakers or agents acting on behalf of the actual owners. The true customers served by transportation infrastructure are the traveling public, consisting of both personal and commercial travelers. Business and personal time clearly have value. Whether for work or non-work purposes, travel time has value, actually a negative value since it reduces the amount of time available for business and personal non-travel activities.

As is the case for any production system, Lean production literature is replete with references to time. These include cycle time, processing time, takt time, queue time, lead time, machine time, etc. The literature also refers to value add time and non value add time. This work expands the concept of value in transportation infrastructure to include the dimension of time.

1.6 Time as Value

Engineer Ohno identified seven wastes or "muda" which included transport. Time spent traveling congested roadways, following detours, or using longer alternate routes due to bridge restrictions or closures is waste. Eliminating travel time waste reduces transportation costs, provides more time for travelers to pursue opportunities, or enjoy more leisure time. Reduced travel time for emergency responders improves public safety, increases survival rates in life or death situations, and provides better protection of property. Moreover, reducing travel time improves the quality of life for those affected. From a Lean perspective, value is typically defined as that which enables the client to better achieve their purposes, which transcends monetary worth. Time is clearly value from this perspective. Why is this a necessary and important point? In terms of the classical triple constraints of cost, time and quality, surrogate owners, specifically the DOT's personnel, tend to place greater emphasis on cost and quality dimensions and insufficient attention on time performance. Meanwhile, the traveling public places greater value on time. The author believes this incongruence results in failure of DOTs to successfully fulfill their mission and duty to the public they serve.

Another reason for the foregoing treatment of time as value is to frame the problem in Lean construction terms. It responds to the challenge issued by Bertelsen to address the topic of value generation and maximizing value for the client (Bertelsen 2004). Again, one of the objectives of this thesis is to suggest Lean approaches to project delivery intended to maximize value and eliminate waste on highway projects.

The Lean Construction community of researchers and practitioners, a.k.a. "Lean Constructionists" do not entirely embrace the classical view of the triple constraints. The prevailing project management conception is that one dimension of the triple constraints cannot be elevated in priority without adversely affecting the other two. In other words, if the emphasis is on time performance, cost will necessarily increase and quality will diminish. Lean project delivery is not structured in terms of the triple constraints, yet its implementation can result in simultaneously satisfying all three dimensions. While Lean Constructionists recognize the reality of the cost-time trade-off, they do not necessarily view the triple constraints as being mutually exclusive, but as concurrently achievable. Lean production systems meet triple constraint objectives without focusing on them. Instead, Lean production is means or process focused with the primary requirements of delivering the product while maximizing value and minimizing waste (Koskela and Ballard 2004, Ballard and Howell, 2004). These requirements coupled with the associated requirement of reducing variability naturally leads to optimizing performance in terms of the triple constraints.

1.7 Assumptions

This thesis assumes the following postulates:

i. Upon signing a contract, the contractor affirms that they are capable of and intend to complete all specified work within the stated contract time frame.

ii. While not all projects are definable as complex, projects tend toward complexity. Highway projects are complex systems that vary in complexity. Time performance is a function of complexity among other factors.

iii. The project management body of knowledge (PMBOK) contains widely accepted time management tools, yet judicious application of these does not effectively prevent duration escalation.

This thesis proposes the following suppositions:

i. Contract duration is generally achievable. Time performance is not a function of the efficacy of the DOT's preconstruction forecasting. Rather, time growth is the result of failure of the DOT to identify risks and/or poor contractor performance. Providing defective designs and inaccurate or inadequate contract documents is an example of failure to identify risks.

ii. It is reasonable to some extent to expect or accept the presence of unforeseen conditions. It is also reasonable to expect or accept that contract documents are not perfect and that interpretations are neither completely clear nor consistent across the entire project team, i.e.: DOT, designer, contractor, subcontractors, suppliers, regulators, etc. As such, effective and timely communication, cooperation, and adaptive behavior are vital in avoiding duration escalation.

1.8 Research Objectives and Expected Outcomes

The predominant research objectives of this work are to assess the current state of highway project delivery focusing on time performance. It seeks to answer the following questions:

1. What is the reliability of forecasted project durations?
2. How frequently are the original contract durations considered achievable?
3. What are the causes of duration escalation?
4. What relationships exist between project variables and time performance?
5. What effect does preconstruction engineering have upon time performance during construction?
6. What effect does DOT-contractor interaction have on time performance?
7. What effect does DOT contract administration have on time performance?

This second objective is open-ended and seeks answers to the following questions:

1. What approaches to management and production from other industries could be successful interventions to address duration escalation on highway projects?
2. How could or should proposed interventions be implemented?

The ultimate product of this work is a set of viable interventions with proposed implementation strategies intended to enhance time performance reliability on highway projects undertaken in the United States.

1.9 Organization of Thesis

This thesis is contains six (6) chapters. Chapter 1, *Introduction* provides the initial background and literature review. Chapter 2 *Research Methodology* describes the planning and design of the HPP Study including a detailed explanation of the survey questionnaire. Chapter 3 is titled *Contemporary Approaches to Construction Planning & Scheduling*. It provides background and critique of contemporary time and project management. The chapter discusses common planning and scheduling practices including methodologies, processes, and philosophies prevalent in the industry. Topics include the necessity and benefits of formal time management, planning tools, and network scheduling; with emphasis on CPM. It also includes a brief review of Earned Value and Earned Schedule Analysis.

Chapter 4 is titled *Highway Project Delivery* and provides an overview of the development and operation of highway agencies, project delivery systems, and procurement procedures. The chapter also provides a brief discussion on typical design development and construction administration. Chapter 5 *Research Findings and Analysis*, presents and assesses the findings of the HPP study. Chapter 6, *Conclusions and Recommendations* includes a brief summation of the HPP Study, proposes an action outline, and suggests future research.

CHAPTER 2: RESEARCH METODOLOGY

2.1 Research Overview

Research methodology included a multifaceted approach comprised of a review of the current literature, expert interviews, and collection and analysis from projects executed by various highway agencies. Literature review covered several relevant topics including scheduling and time management, project management tools and techniques, complexity in projects, innovative project delivery, Lean production systems including Lean construction, and supply chain theory. Review topics further included highway planning, design, and construction; constructability concepts and analysis; and risk management in project development and construction. Current research literature included studies performed under the sponsorship of the National Cooperative Highway Research Program (NCHRP) through the Transportation Research Board (TRB) and American Association of State Highway and Transportation Officials (AASHTO)

The major research focus of this thesis was the Highway Project Performance (HPP) Study. The HPP study objective was to gain a better understanding of current highway project performance. This included determining the frequency and magnitude of project time growth; or duration escalation. It further included identifying the input variables of processes, conditions, and constraints under which typical highway projects are delivered. The assessment included identifying relationships between the explanatory input variables and the dependent outcome variables in order to gain a deeper understanding of time performance and duration escalation on highway construction projects. The assessment was based on empirical data collected from highway construction projects completed in the Northeastern and Mid-Atlantic regions of the United States. The projects were limited to those completed within the six-year period of 2006 through 2011 with a targeted minimum original contract cost of $2 Million. Paving rehab projects were excluded from the study.

A printed questionnaire served as the data collection instrument and was designed to elicit information sufficient for comprehensive analysis of project performance. The author developed the initial iteration after numerous conversations with SMEs from diverse areas of expertise. These SMEs included transportation industry professionals, project management practitioners, and experts in Lean construction systems. The Delphi Method was employed for refinement of the data collection instrument, resulting in four (4) iterations leading to the semi-final version[1]. Participants in the Delphi exercise included seasoned highway agency practitioners from the Pennsylvania Department of Transportation (PennDOT), New Jersey Department of Transportation (NJDOT), and the Delaware Department of Transportation (DelDOT). All of these SME's have extensive experience managing highway projects, each having over 20 years of industry practice. The individual SMEs were asked to review the data collection spreadsheet to:

1. Determine whether the requested data was of sufficient breadth and depth necessary to gain a new understanding of highway project performance in terms of the stated criteria. Would the requested data lead to explanations of project outcomes?
2. Identify questions that appear ambiguous, unclear, or misleading
3. Determine the degree of difficulty in gathering the requested data

[1] Using the Delphi Method, SMEs answer questionnaires in two or more rounds. In between each round, an anonymous summary of the SMEs' answers from the previous round are shared with the panel. The SMEs

The SME review of the data collection spreadsheet was very productive. The initial request for review and feedback received favorable responses. The feedback was delivered via email responses, telephone conversations, and face-to-face meetings. The data collection instrument went through four iterations as a result of the feedback received from the SME Panel. The data collection instrument was also modified based on input from the full Ph.D. Committee and CAEE Faculty, Joseph V. Mullin, Ph.D., P.E.

2.2 Pilot Study

A pilot test of the data collection instrument was conducted on seven (7) DelDOT projects. Pilot test results provided insight into the efficacy of the data collection instrument and research protocol. The pilot test revealed that the semi-final questionnaire was too long and somewhat cumbersome. Follow-up discussions with survey participants revealed reluctance to complete the survey based on the length of the questionnaire. Analysis of the collected data revealed superfluous or irrelevant information that did not prove useful for the study. As a result, the data collection instrument was reduced from eleven (11) pages to a 4-page questionnaire. The revised questionnaire includes additional questions required to fill the information gaps revealed in the pilot study and subsequent literature review. The new 4-page questionnaire was reviewed by the full-committee and further evolved through five (5) iterations leading to the final version.

The final questionnaire was printed double-sided onto 11” x 17” sheets. Appendix A includes full-size single sheets of the questionnaire. In addition to the hardcopy instrument produced in Microsoft Excel, the questionnaire was converted to a web-based survey using SurveyMonkey™[2]. The Excel and SurveyMonkey versions are essentially identical. The differences are quite minor and are generally a result of format limitations associated with the web-based version. All of the survey content and questions are identical. Screen shots of the SurveyMonkey questionnaire are included in the Appendix.

The questionnaire begins with an introductory statement on Page 1 and ends with a closing statement on Page 4. The opening statement reads:

> *The United States faces an infrastructure crisis in which deteriorating bridges and highway congestion threaten the economic prosperity and quality of life associated with travel mobility. Transportation professionals are challenged to do more with less in half the time. In response, the Department of Civil, Architectural, and Environmental Engineering at Drexel University is conducting a study to assess current practice and identify strategies to enhance project delivery. This questionnaire is a valuable tool designed to aid in the investigation and understanding of current highway project performance. Your participation in this survey is not only appreciated, but vital to the success of this project. All information is strictly confidential and will be used only for comparative analysis and better understanding of project performance. The final results will be shared with all respondents*.

[2] SurveyMonkey is a provider of commercially available web-based survey solutions headquartered in Palo Alto, CA.

The closing statement reads:

Thank you for taking the time to complete this questionnaire. The collected information shall not be used to criticize or denigrate any project, organization, or individual. Furthermore, reports of the findings shall not reveal performance of specific projects; identify individual contractors, designers, agency employees, etc.; reveal performance of individual agencies to others; single out any one project for any reason - positive or negative. For the sake of objectivity and shielding of participants, the text will not report or categorize the data by state, municipality, or agency but by engineering classifications only. We will be sure to provide you with a report of the findings from this study.

2.3 **Design of the HPP Study**

The questionnaire was intended to elicit both quantitative and qualitative empirical data. All of project data were collected from the agencies representing the owner's perspective. The agencies included in this study are limited to those located in the Northeastern and Mid-Atlantic regions of the United States from Pennsylvania, New Jersey, New York, Delaware, Maryland, Virginia, West Virginia, and North Carolina. These agencies included PennDOT, DelDOT, NJDOT, New York State Department of Transportation (NYSDOT), Maryland State Highway Administration (MDSHA), Virginia Department of Transportation (VDOT), West Virginia Department of Transportation (WVDOT), North Carolina Department of Transportation (NCDOT), the

Delaware River and Bay Authority (DRBA), and the City of Philadelphia Department of Streets.

The respondents were engineering management professionals working for the participating agencies serving in the capacity of Area Engineer, Project Manager, or Resident Engineer. These individuals represent the owner's perspective and generally possess intimate knowledge of the projects to which they are assigned. Given the general depth and breadth of experience typically required of professionals in these roles, i.e. area engineer, project manager, or resident engineer, it was assumed that they have a reasonably reliable frame of reference against which to compare subject projects. The respondents were instructed to:

1. identify five (5) or more projects completed within the last 5-years for which you have access to the contract records
2. limit selection to original contract values greater than or equal to $2 million
3. exclude paving rehab projects
4. do not select or restrict projects based on whether they were good, poor, or average performers…do not discriminate one way or the other
5. place the name of each project in a hat and draw one project
6. complete the questionnaire for the "drawn" project
7. complete the entire questionnaire
8. be as honest, accurate, and objective as possible

Multiple projects may be submitted and are in fact appreciated provided that:

a) one questionnaire is completed per project

b) additional projects are selected random

One questionnaire was completed per project. The questions on the first page were intended to identify the project and obtain categorical data based on engineering classifications. The pages that follow include questions to identify management processes, conditions, and constraints under which the project was executed. The questionnaire was designed to educe reasons for post-award cost growth and project duration escalation. The next section extracted performance-related data using a seven-point Semantic scale to measure the responses. Several of the performance–related questions were posed as comparisons against the "typical project". These questions were intended to gauge the quality and constructability of the contract plans, the effectiveness of the contractor's schedule, and the level of trust and cooperation between the DOT and the contractor.

The investigation attempted to determine the correlation between time performance and project complexity. A question intended to measure the level of project complexity was preceded in the questionnaire by a statement containing the complexity criteria believed relevant to highway construction. Fifty (50) highway engineers from the Northeast and Mid-Atlantic regions were polled to confirm the validity of the statement defining complexity in highway projects

Of the 50 polled, 39 engineers with an average of 33 years of experience in the highway industry responded. 37 of the 39 responded positively. This translates into a 76% response rate with 95% of the respondents validating the complexity criteria. The nature of project complexity is a subjective and a somewhat contentious issue, so it was important to identify and validate common criteria. Understanding the relationship between complexity and time performance is a valuable element of this study. Defining project complexity in the context of highway construction is an important first step.

2.3.1 Categorical Information

Project demographic or categorical information included Life Cycle Stage, Division of Work, Location, Functional Class, Primary Purpose, and the Range in terms of dollar value. Life Cycle Stage gauges whether the work was new or restoration/reconstruction/rehab/retrofit. The Division of Work addressed whether the projects consisted of roadwork, roads with bridges, or bridge work only. In this context, the Location category is an engineering classification designating the setting of the highway as either situated in urban, small urban/ suburban, or rural environs. Functional Class is another engineering classification denoting whether the project affects a primary arterial, minor arterial, collector, or local road.

Another categorical question sought to classify projects in terms of Primary Purpose. The questionnaire offered four choices: increase capacity/improve traffic flow, restoration/maintain function, upgrade structural capacity, or safety improvement. While many highway projects are launched for a combination reasons, the question sought to identify the primary driving purpose. It is entirely possible that improving the function of a stretch of roadway could also result in improved safety for the motoring public and pedestrians alike. Upgrading the structural capacity could in fact improve traffic flow and function and also result in enhanced safety for the public at-large. Obviously, these purposes are not mutually exclusive but the objective of this question was to isolate the single driving purpose of the work.

The next categorical question addressed the size of the project in terms of total cost range. Highway industry professionals and legislators often refer to the size of a project as its total dollar value. The Size/range $ value bins were selected to conform to those used in previous research in order to facilitate any potential comparisons that may be warranted. The four Size/range dollar values employed include 2 - 4 Million, 5 - 20 Million, 21 - 35 Million, and > 35 Million. This author has observed in practice that higher dollar value projects typically warrant and receive greater attention in terms of project management effort. Previous studies have found direct correlation between post-award cost growth with time escalation. While the questionnaire includes queries to identify the original contract dollar amount and final cost, the Size/range category facilitates sorting and filtering.

Project Delivery is a category that could also be termed Project Procurement Method. The project delivery methods are the general types typically used to design and construct highway projects. These include Design-Bid-Build (DBB), Design-Build (DB), CM@Risk, and Public-Private Partnerships (PPP). The traditional Design-Bid-Build method remains by far the most prevalent within the highway industry. Design-build is more prevalent in some states than others. Public-Private Partnerships have been limited in the United States, but may continue to gain acceptance as a viable delivery method due to the funding shortfalls experience by most State DOT’s. The choice of delivery method can have a significant impact on project outcomes and is an important characteristic to track.

The final category is “Designer”. The question was not framed to identify the specific designer of record, but to distinguish whether the essential design function was performed by the owner’s in-house staff, a consulting engineering firm, a design-builder, or if the project was built according to an approved contractor alternate scheme. Most State DOTs have some in-house design capacity and at least provide plan review of designs completed outside of the agency. Design-builders take a few different forms. In the highway industry, most design-builders are general contractors that employ consulting engineers essentially as subcontractors to complete the design. In this respect, the highway industry is not like various commercial and residential building sectors in which integrated design-build teams are prevalent. Such integrated teams directly employ design as well as construction professionals under the same roof within a single firm. The design and the emanating contract documents, i.e. plans and specifications provide the framework for project execution, thus the design professional’s product largely affects work in the field.

2.3.2 Contract and Performance Data

Elemental contract information and performance data was obtained through open-ended questions within the questionnaire. Such questions included the First Chargeable Day and the Contract Completion Date. The original contract duration (OCD) and the final construction duration (FCD), both listed in calendar days (CDs), were explicitly identified through independent open-ended questions. The FCD may or may not be derived by the difference between the First Chargeable Day and the Contract Completion Date due to special contract terms or clauses, unique circumstances, or agreements negotiated between the owner and contractor. Time variance (**Δ**t) is a key performance indicator, which is the difference between OCD and FCD and the determination thereof is an essential piece of this study. A negative **Δ**t value indicates that the project exceeded its originally allotted contract duration and is referred to as time escalation (TE). Another way of expressing time variance is as a percentage of the OCD (Δ_{TIME}%) The time performance index (TPI) is a key performance indicator that is obtained by dividing the OCD by the FCD. The TPI while similar should not be confused with the schedule performance indicator or index (SPI) used in Earned Value Analysis. The SPI is derived by dividing the earned value (EV) by the planned value (PV) and is a project management tool for analyzing and describing progress. The SPI is not valid for time beyond the OCD. Like the SPI, the TPI is an indicator of efficiency. TPI values ≥ 1 are seemingly favorable results indicating that the project finished on or ahead of schedule, while a TPI < 1 indicates that the project finish beyond the OCD.

The questionnaire included an open-ended question regarding time extension granted to the contractor in terms of CDs. A follow-up open-ended question considered that if a time extension was granted, how many CDs were granted in specific response to weather delays.

A discrete question with a yes or no answer followed the questions related to time. The question read “Based on the original scope of work without considering the effect of weather, was the original contract duration reasonable and achievable?” While this question and others that follow are subjective in nature, the respondents are all seasoned highway engineering and construction professionals. The respondents are considered expert in this regard by virtue of their knowledge, experience, and position within their respective agency. Many respondents are licensed professional engineers.

While time is the central theme and concern of the study and thesis, cost cannot be overlooked. Time and cost are interdependent, along with quality. There exists a very definite time-cost-quality trade-off. Therefore, construction costs are addressed in open-ended questions. These questions quantify the original contract amount and the final or actual construction cost. The difference (original cost – actual cost) is a key performance indicator referred to as the cost variance (**Δ$**)[3]. A negative **Δ$** value indicates a budget overrun and is defined as the post-award cost growth. Other key performance indicators based on cost include the cost variance as a percentage of the original cost ($\mathbf{\Delta}_{COST}$%) and the final cost performance index (FCPI), which equals the original contract cost divided final (actual) contact cost[4].

Other open-ended questions concerning cost include identifying the difference between the winning bid and the second-place place finisher. It is believed that successful low bidders that "leave a lot on the table" will have small (or no) profit margins and may be more likely to exhibit sub-par performance or file claims against the owner to make up the difference[5]. This price difference can easily be calculated and viewed as a percentage of the low bid price for further analysis. Another open-ended cost question determines the difference in the low bid compared to the Engineer's Estimate and whether that difference was over or under. This amount can be used to easily compute the difference in terms of a percentage of the contract price.

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[3] The **Δ$** is similar but not the same as the cost variance (CV) found in Earned Value Analysis or Earned Value Management, where CV = Earned Value (EV) – Actual Cost (AC). The CV is a snap shot measure at a data during the execution of a project. The **Δ$** in this context is a measure of final performance.
[4] The FCPI is similar but different from the CPI used in Earned Value Analysis. The CPI indicates the cost efficiency up to a given data date and is computed by dividing the Earned Value (EV) by the Actual Cost (AC) at the given point in the project execution phase. The FCPI reflects the cost efficiency of the completed project.
[5] "Leaving a lot on the table" is industry slang for the low bidder submitting a price that is significantly lower than the second lowest bid amount.

The questionnaire also sought to identify the daily amount listed for liquidated damages in the contract documents for each project. As is the case with the previously mentioned cost differentials, liquidated damage amounts can be viewed in terms of percentages of the original contract value. Liquidated damages are predetermined remedies for breach of contract listed in the contract specifications. In the case of liquidated damages, the breach of contract is late completion beyond the original contract duration or completion date. Courts in the United Stated have held that liquidated damages may not be punitive in nature. Higher dollar amounts for late completion penalties must be balanced by the opportunity for the contractor to receive a bonus. These amounts are more properly referred to as incentives and disincentives. The questionnaire addressed whether Innovative Contracting Methods or Procedures were employed on the project including offering an incentive/disincentive to encourage timely completion of the work. The question group allowed an open-ended response to indicate the incentive/disincentive dollar amount, if applicable. Common belief within the industry is that liquidated damage amounts on highway project do not provide sufficient motivation to affect timely completion. Incentive/disincentive clauses may be more effective in that regard.

2.3.3 Constraints

The next section of the questionnaire was intended to identify the constraints under which the project was executed. In the context of this study, a constraint is any external system, factor, or element that can hinder or impede progress during construction. Constraints affect or limit and certainly shape the contractor's execution of the work. Constraints can be physical or legal[6]. Physical constraints can be naturally occurring or man-made. Constraints as defined herein do not necessarily align with the Theory of Constraints (TOC) introduced and defined by the late Dr. Eliyahu M. Goldratt (Goldratt 1984, 1997). Dr. Goldratt includes internal factors such as resources and company policy in addition to external sources. The TOC was partially adopted by Glenn Ballard in creating the Last Planner™ System of Production Control (Ballard 2000). However, this study considers only external factors as constraints. As such, these constraints would be the same for a given project regardless of which contractor was awarded the job. In the TOC philosophy, this would not be the case since internal policies and resources vary from contractor to contractor.

The constraints considered in the study and incorporated in the questionnaire include wetlands, parklands, archeological sites, historic landmarks, fish and/or wildlife, streams or waterways, navigation, winter shutdown, phased maintenance of traffic (MOT), physical space, built environment, noise ordinance, utilities, holidays, environmental mitigation, railroad, union contract, and Force Majeure. All of these "constraints" meet the definition previously articulated. Any one of these constraints could hinder or impede execution. Many projects actually operate under multiple constraints. Whatever the case, the constraints on a given project would be the same for all qualified bidders[7].

Wetlands pose restrictions that are both physical and legal in nature. The physical aspects of working in or around wetlands include soil that is at least periodically or seasonally wet to the point of saturation. The soil in low lying marshy wetlands can often

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[6] Legal constraints can be statutory, regulatory or contractual in nature.

[7] The one exception might be the union contract. However, most collective bargaining agreements in construction apply uniformly to all union contractors within a given jurisdiction and industry sector such as public infrastructure.

be classified as muck which is soft, plastic, and compressible and often extends to significant depths. Some wetlands cover formations of peat which is also organic and compressible. All of this translates into soft, unstable and generally weak ground conditions that affect mobility across the construction site. Specialized equipment and bridging material such as heavy timber mats are required for mobility and to maintain stability in lifting operations. Construction of permanent features such as road boxes, utilities, and structures require measures beyond those normally required for the same elements or systems outside of wetlands. While the physical nature of wetlands can be daunting, the legal aspects can be even more so.

Wetlands are regulated by the U.S. Army Corps of Engineers (USACOE) as a result of the Clean Water Act (CWA) in 1972. Section 404 of the CWA include regulation of wetlands. Proposed activities in wetlands are regulated through a permit review process and enforced by the USACOE. This includes both permanent and temporary construction activities. Excavation and placement of fill is restricted. Permanent construction such as embankments requires mitigation of the lost wetlands by creating new wetlands from land that was previously dry. Owners including State DOTs and other transportation agencies are typically responsible for securing the necessary permits. The contractors working under these permits are required to comply with all general and special conditions. These general and special conditions are or certainly should be included in the special provisions of the contract, thereby compelling the contractor into compliance through regulatory law and contractual obligation. Requirements include submission and approval of designs for temporary access. The contractor's personnel and equipment are typically restricted to approved temporary access paths. No fueling or equipment maintenance is permitted within wetland boundaries. Heavy fines and even imprisonment are penalties for violating conditions of the permit or 404 regulations. The project can be suspended and in extreme or repeat cases of non-compliance, the owner can terminate the contract. It is obvious that these significant physical impediments and legal restrictions associated with working in wetlands can impede the execution and flow of work.

Environmental or wetland mitigation is often incorporated in highway contracts. "A mitigation bank is a wetland, stream, or other aquatic resource area that has been restored, established, enhanced, or (in certain circumstances) preserved for the purpose of providing compensation for unavoidable impacts to aquatic resources (EPA 2011 http://www.epa.gov/owow/wetlands/facts/fact16.html, 08/07/11 6:50 PM)." Land within or adjoining the project site may serve as a mitigation bank. A contract could just as well include a remote site for a mitigation bank. Mitigation work includes excavating to reduce normally dry land into wetland. The soil excavated from the mitigation site may be used for roadway embankments requiring close coupling between cut and fill operations. Mitigation work eventually requires excavation and grading in wet conditions not normally encountered in typical roadwork. Such excavation may be performed by draglines or clamshell buckets. The wet material generally requires special handling to promote drying prior to incorporation into the new work. In many cases, the timing and success of the project is dependent upon the timing and success of the environmental mitigation work.

Parkland includes national and state forests but can also include wooded areas and open space in individual communities. These can include public parks, greenbelts and other undeveloped open spaces, pedestrian and bicycle trails, playfields, and school district play areas that are available for public use during school off hours. The

Department of Transportation Act (DOT Act) of 1966 included a special provision, namely Section 4(f), which restricts the use of land from publicly owned parks, recreational areas, wildlife and waterfowl refuges, or public and private historical sites. Parkland often comes under the jurisdiction of the U.S. Department of the Interior with administration and enforcement provided through the National Park Service. In addition to federal regulation, parklands are also subjected to state and local regulation.

An archaeological site is a location in which evidence of past activity, either prehistoric or historic is preserved and is investigated to secure the archaeological record. An historic landmark is a building, site, structure, grave, monument, or other object that is officially recognized for its historical significance. It can further include an entire district. It can be nationally recognized as a National Historic Landmark or merely enjoy local recognition. The previously mentioned Section 4(f) of the DOT Act does to some degree cover sites of archeological and historical significance, as does the 1966 National Historic Preservation Act (NHPA). All 50 states have State Historic Preservation Offices (SHPO) that work to protect archaeological and historic resources and the rules and regulations vary from state to state. Contractors working adjacent to such sites are required to avoid and protect these recourses. Having archeological and historical sites in close proximity can significantly hamper construction operations. Activities such excavation, blasting, and pile driving are often limited and closely monitored. Sites of archaeological interest discovered after notice to proceed (NTP) can bring construction activities to a grinding halt. Whatever the timing, archaeological and historic resources within or adjacent to project limits requires special care and can impede the normal execution and flow of construction.

Streams and waterways are also regulated by the USACOE under Section 404. States, counties, and local municipalities also exert regulatory authority and enforcement. Prior to the 1970's, a contractor installing a bridge abutment or a sewer crossing could temporarily divert a stream in whatever fashion suited the situation and then simply remove the diversion after completion of the work. Today, even the smallest and simplest stream diversions may only be performed under permit and strict scrutiny. Activity in and around streams must be planned and approved well ahead of the actual field operations; if it is permitted at all. There is often very little or no leeway in adherence to approved details.

In addition to regulatory restraints, streams and waterways also pose obvious physical challenges. This includes depth and velocity of the stream flow under normal conditions; substantially increased by storm events. Turbulent flow and resulting eddying currents can occur at obstructions such as cofferdams, making access all the more difficult and dangerous. Tidal waters provide additional challenges beyond normal and storm flows. Streams and waterways in the Northeast and Mid-Atlantic regions of the United States are prone to ice formation and ice flow, which can impede progress and pose hazards to the work and workforce. Some waterways may be designated as navigable waters of the United States. As such, these are under federal jurisdiction regulated by the USACOE, not States or municipalities.

Waterways that provide a channel for commerce and transportation of people and goods are defined as navigable waters. Under federal law, bodies of water are distinguished according to their use. In 1979, the U.S. Supreme Court stipulated four tests for determining what constitutes navigable waters[8]. The tests ask whether the body

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[8] Established in Kaiser Aetna v. United States, 444 U.S. 164, 100 S. Ct. 383, 62 L. Ed. 2d 332

of water (1) is subject to the ebb and flow of the tide, (2) connects with a continuous interstate waterway, (3) has navigable capacity, and (4) is actually navigable. Based upon results of these tests, courts have held that bodies of water much smaller than lakes and rivers also constitute navigable waters. Even shallow waters that are negotiable only by canoe have met the test. Whatever the case, construction operations may not impede or create addition hazard to navigation. Construction operations can and should be scheduled around vessel passage can schedule. However, unscheduled passage is not uncommon, causing unplanned and costly delays. Construction operations in navigable waters demand a high care standard of care and ultimately affect the timely flow of work.

Greater awareness and concern has grown in recent decades concerning the effects of urbanization and highway construction on fish and wildlife. As a result, planning, design, and construction or reconstruction of highways must include measures to minimize impacts to fish and wildlife passage or movement and preserve habitats. Hydrological structures may not be adequate to allow the necessary movements, thus crossing structures specifically for wildlife passage are often included in roadway designs. This applies to both fish passage and wildlife movement not only in the final configuration but also during construction. Contract specifications may limit or restrict work during seasons of spawning or migration. Access to streams and other parts of the construction site may be limited or at least regulated. Such restrictions may be a matter of regulatory law and likely reflected in the contract's special provisions.

Utilities and railroads are two systems that can significantly impact project execution. The terms "utilities" and "railroads" both have a double meaning. They refer to the physical infrastructure and also to the entities that own and operate the facilities. Early involvement of utility and railway companies in the preconstruction planning and design phase(s) is critical. However, earlier involvement of these critical stakeholders does not guarantee minimal impact during execution. These stakeholders have their own interests, which often do not align with those of the DOT. Their priorities naturally are focused on their own operations, not the DOT's. Each State DOT organization includes a Utility Section or Group on some level, which serves as an immediate liaison to utility and railway companies during planning, design, and construction. Each State DOT typically has their own set of guidelines for dealing with utilities and railroads. The FHWA and AASHTO also have guidelines and recommended best practices, which are available to the State DOTs and other transportation agencies. Various National Cooperative Highway Research Program (NCHRP) projects administered by the Transportation Research Board (TRB) have been launched to identify new strategies and technologies for working with utilities on highway projects[9].

Utility transmission and distribution systems typically occupy State, county, or local public right-of-way, either aerially or underground. "Accommodating public utilities on highway right of way has traditionally been at no cost to the utility or only involves direct cost reimbursement for replacement ROW. This reflects society's public service policy that supports limiting the burden on taxpayers for basic municipal services (FHWA 2011 http://www.fhwa.dot.gov/realestate/rowutil1.htm 8/8/11, 3:15 PM)." These policies are reflected in State law governing the public right-of-way and public utilities. Generally, when existing utilities unavoidably conflict with new construction or reconstruction of a bridge or section of roadway, the utility company(s) must adjust or

[9] One such initiative is "Advancing Technologies for Working with Underground Utilities." It is part of the current SHRP 2 Research conducted in cooperation with the FHWA and AASHTO. The initiative includes four active utility-related research projects: Technologies for the Storage, Retrieval, and Utilization of 3-Dimensional Utility Location Data (R01-A); Multi-Sensor Platforms for Locating Underground Utilities (R01-B); Development of Innovative Technologies for the Location of Deep Utilities (R01-C); and Identification of Utility Conflicts and Solutions (R15-B).

relocate their facilities. Some of these conflicts can be identified and addressed in the preconstruction phase. However, utility companies may only possess marginal as-built location information. "We don't know where utilities are (James Anspach, SHRP 2 Webinar)." This is common especially in older, urban settings such as colonial cities and towns in the Northeast and Mid-Atlantic United States. This lack of subsurface information increases the risk to the DOT, contractor(s), and utility owner. Unforeseen or differing site conditions impede the execution and flow of work, often impacting multiple chains of activities. Even when the conflict is identified in the preconstruction phase, utility companies are often slow or even unresponsive in addressing the problem. The direct delays are sometimes compounded by the initial disruption caused in the field. This might include subcontractors temporarily demobilizing from the job and the ensuing lag in returning to the site after the utility conflict is mitigated. Significant compounding beyond the initial utility delay can occur when contract work is pushed into winter during which certain operations cannot be efficiently executed or even executed at all.

Interface and conflict with railroads is less common than with utilities, but no less impactive. The rail companies voraciously protect railroad right-of-way, whether the line carries freight or passengers. In many locations, the rails carry passenger trains by day and freight by night. State DOTs and other highway agencies must negotiate with rail companies to gain temporary access to railroad right-of-way and establish the terms and conditions upon which the highway work can be executed. These terms and conditions become part of the contract between the DOT and contractor. These conditions include working hours adjacent to track and available windows of time for working over the tracks. These windows can be as little as two hours in early morning, e.g. 2:30 – 4:30 AM for Amtrak mainline facilities. Even these meager windows are subject to frequent cancellation with no recourse for the contractor or DOT. Other conditions include special insurance requirements, clearances between track and stored equipment or materials, grounding of equipment, watchmen and flaggers, personal protective equipment, training, and other considerations important to the railroad. Working over or adjacent to freight rail is very difficult. Working over or adjacent to passenger rail is extremely difficult with many challenges and restrictions and obviously fraught with substantial impediments to predictable, timely flow of work.

Many projects require that the safe flow of traffic be sustained through the construction period, typically requiring phased maintenance of traffic (MOT). MOT is typically a contract requirement imposed upon the contractor, affecting all or part of the construction duration. It requires that the traveling public and highway construction crews are adequately protected while conducting traffic at all or some portion of its normal flow. As such, MOT is a planned system of phases as well as physical delineation and separation. MOT may also include provisions for pedestrian movements. MOT schemes are usually generated by the project's designer-of-record during the various design phases. It is not uncommon for contractors to develop and submit alternative MOT staging and alignments after award of the contract and even late into the construction period. MOT phasing varies in complexity depending upon several factors including functional classification, situation (location), speed, number and location of connecting or intersecting roads, available space, grade differences, structure demolition or erection sequence, stormwater management, and several other considerations. MOT requirements obviously constrain the execution of work. Successfully highway contractors typically exhibit a high degree of competency in MOT operations. They incorporate MOT milestones within their schedules and use these events to maintain takt time towards timely project completion.

Physical space limitations may be present due to naturally occurring or man-made physical features. Physical space limitations may also be due to narrow right-of-way or the absence of sufficient temporary construction easement. While physical space constraints are common in urban environments, such impediments may also be present in rural settings. Space limitations can impede the execution and flow of work on any type of construction project including highway work. One of the advantages of a Lean construction site is the optimization of space through just-in-time deliveries and 5S methodology[10].

Space restriction is only one manner in which the built environment can impact or impede execution and flow of construction operations. There are many others. Buildings, roadways, sidewalks, parking lots, driveways, various appurtenances, etc. that adjoin the project must have proper interface with the new work. This requires careful vertical and horizontal alignment. It also mandates that physical connections or tie-ins be made without damaging the existing features. Buildings must be safe-guarded against damage not only from direct impact but from vibration caused by heavy equipment, compaction effort, pile driving, and of course; blasting. Foundations may require underpinning or some other type of protection. Dewatering can cause subsidence in adjacent structures and cannot be performed indiscriminately. There are certainly many factors related to the built environment which increase the DOT's and the constructor's risk and impede the progressive flow of work.

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[10] 5S is the name of a workplace organization methodology that uses a list of five Japanese words which are seiri, seiton, seiso, seiketsu and shitsuke. Transliterated or translated into English, they all start with the letter "S" and include sorting, straightening, systematic cleaning, standardizing, and sustaining.

Working within the built environment may also pose restrictions that are not the result of interface with physical features. Such is the case with noise ordinances. These are laws that are passed and enforced on the local level by the county, city or other municipality. Noise ordinances have the effect of restricting construction work hours. A noise ordinance limits the amount of noise, duration of noise, and sources of sound other than ambient noise that affects a residential community. A noise ordinance usually applies at night during the times when most people sleep and sometimes on weekends when certain types of noise can interfere with relaxation. Sounds produced by construction operations that would violate most noise ordinances include loud engines such as those on heavy equipment, generators, light plants to name a few. Air compressors, jackhammers, grinders, compactors, and power tools in general are all sources of violation. Of course, pile driving, blasting, and demolition are sources of violation. Shouting and loud talking common on construction sites are also sources of violation. Obviously, noise ordinances can be quite restrictive and limiting in terms of available working hours.

Force majeure is a French term meaning "superior force" or “casus fortuitus” from the Latin. A force majeure is an extraordinary event or scenario beyond the control of the owner or contractor. Events that would constitute and force majeure include Acts of God, such as flooding, earthquake, mudslide hurricane, or tornado. Other events that would constitute a force majeure include wildfire, war, riot, insurrection or political upheaval, and strikes. In legal terms however, a strike by a union with whom the contractor is party to a collective bargaining agreement may not be considered force majeure since the strike may have occurred as the result of an action or inaction on the part of the contractor. Whatever the case, a force majeure is quite disruptive, perhaps to the point of being catastrophic.

A qualitative question followed the section on constraints asking, "How adequately were the applicable constraints addressed in the contract documents?" The response option was a 7-point semantic scale with 1 being "Inadequately" and 7 being "Quite adequately". The question was intended to gauge how well the documents identified the various constraints present and what measures were included to effectively mitigate such presence.

2.3.4 Coordination with Regulatory Agencies

The next group of questions was intended to identify coordination requirements with regulatory agencies including the Federal Highway Administration (FHWA), the U.S. Army Corps of Engineers (USACOE), and various State Departments of Environmental Protection (DEP, DNREC, etc). These third-party agencies impose certain requirements by law upon the owner (DOT), which trickle down to the contractor and subcontractors. Preconstruction involvement with these agencies includes plan review and approval. FHWA interests are driven by the fact many State projects are federally funded an as such come under Administration scrutiny. FHWA oversight often continues into the construction phase of the project life cycle. Their interests include issues related to cost, schedule, quality, safety, and contract administration including general compliance with all contract documents. The FHWA will reserve the right to review all proposed plan revisions and change orders and may conduct periodic visits to the site. The environmental application and review process dictates preconstruction interface with the USACOE and the State DEP. During construction, these entities enforce compliance with regulatory law and permit conditions, when applicable. Any plan changes or shop drawings related to permit conditions would have to be reviewed and approved by these agencies before implementation. Interaction with any one or combination of activities can affect construction progress.

2.3.5 Time Management Methodologies

The coordination requirements section was followed by a question that sought to identify specific time management methodologies or techniques that were used to plan, execute, and monitor construction work. The response choices included CPM Scheduling, Linear Scheduling Method or Line-of-Balance, and Last Planner™. The question did not ask what exact method within CPM, e.g. ADM, PDM, etc. Nor did it seek to identify what specific software was employed, e.g. Primavera product, Microsoft Project, Vico software, etc. The three choices are considered mutually exclusive. Last Planner™ typically employs either CPM or LSM in master scheduling, but Last Planner™ would be the parent methodology in either case.

2.3.6 Innovative Contracting Methods or Procedures

The question that followed asked if one or more Innovative Contracting Methods or Procedures were applied on the project. These include Incentive/Disincentive Clause, Best Value Procurement (Adjusted Score Selection, A+B), Qualifications-based Selection, Lane Rental Method, Value Engineering Study, Constructability Study, and Formal Pre-construction Risk Assessment. As previously mentioned, an Incentive/Disincentive Clause provides monetary motivation for timely completion.

Qualifications-based Selection is a method of selection in which an owner chooses an architectural or engineering consultant based solely on qualifications such as a proven track record of experience, understanding of the work under consideration, and other competencies critical to the success of the project under consideration. Traditionally, it was rare for a construction contract in public highway work to be awarded through qualifications-based selection. However, some States' procurement laws are changing to allow a move toward more qualification-based selection of contractors for highway projects. A hybrid method of selection combines the features of qualification-based selection with low-bid selection. The method is termed "Best Value Procurement" which includes Adjusted Score Selection; often referred to as A+B Selection or Cost+Time Bidding.

An Adjusted Score A + B is determined from a price proposal combined with a proposed contract time multiplied by a time value cost. Adjusted Scores can also include factors or scores for technical merit. Some adjusted scores include other factors such as safety. In the case of safety, the score is adjusted by the bidder's current Experience Modifier to favor those with a superior record of safety performance[11]. Adjusted scores can include performance scores from previous years or projects. Of course, an agency's ability to use Adjusted Score Selection or any Best Value procedure is based in that State's procurement laws. The example shown in Figure 1 illustrates the Adjusted Score Selection used by Florida Department of Transportation (FDOT) to procure a design-builder firm for major design-build projects. In the example shown, three design-build firms were short-listed in which each submitted separate price and technical proposals. The "A" component is the proposed bid price and the "B" component is comprised of the

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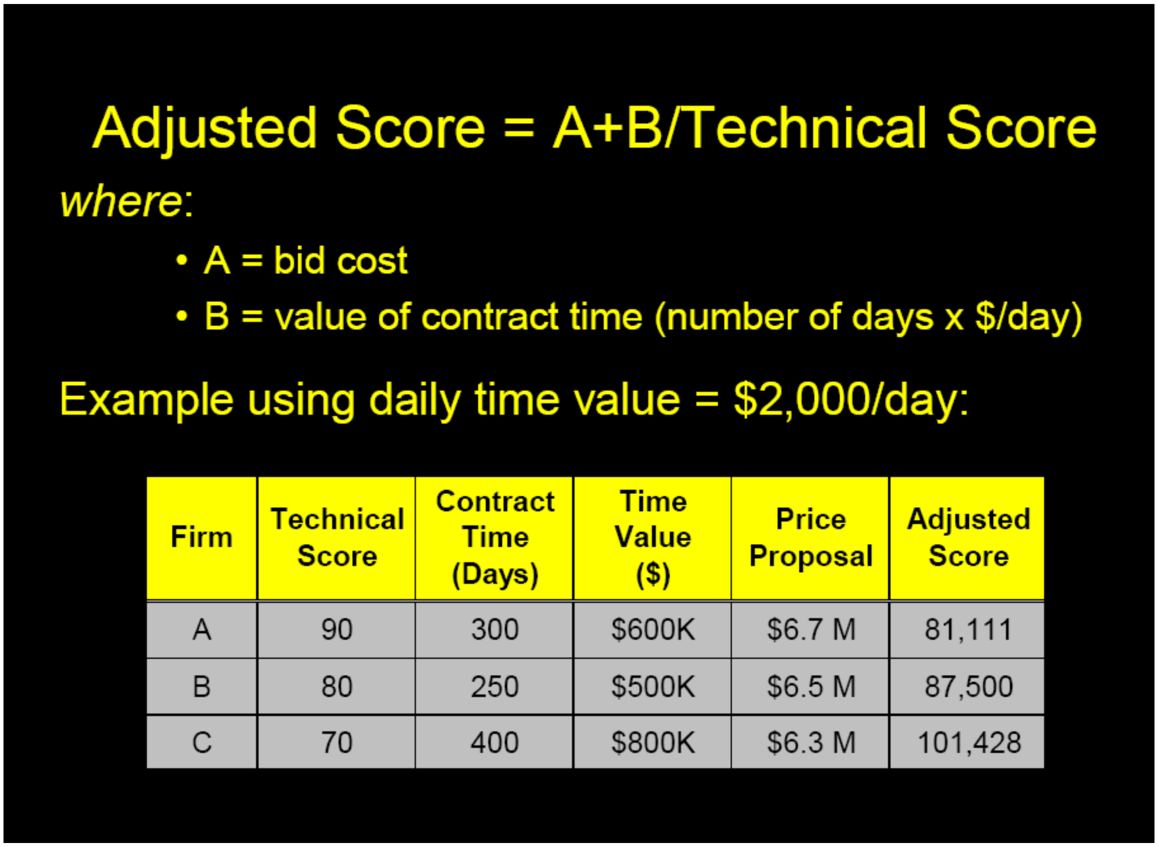
[11] Experience modifier or experience modification is a factor used in the insurance industry, specifically in workmen's' compensation insurance. It is used to adjust the premium based on previous loss experience. Typically, three years of loss experience are used to determine the experience modifier for a workman's compensation policy. This typically does not include the immediate past year, but the previous three years.

design-builder's proposed project duration for design and construction phases multiplied by the value of contract time. Each team proposes project duration. The dollar value of contract time is stated in the formal Request for Proposal (RFP). The example below considers technical merit by dividing the sum of A + B by the score of the technical proposal. In Florida, FDOT's Technical Committee reviews each firm's technical proposal only. The Committee does not see nor have access to the firms' proposed bid price or proposed contract duration. The design-builder with the lowest adjusted score is selected to complete the project. The virtue of this method is that competitive low bidding is tempered by technical competencies and other factors important to the owner. The technical score in this case reflects the quality and suitability of the proposed preliminary designs completed by each of the short-listed firms. In the example shown, Firm A submits the highest price proposal but is the winner based on a higher technical score than Firms B and C and has a lower proposed project duration than Firm C.



Firm	Technical Score	Contract Time (Days)	Time Value ($)	Price Proposal	Adjusted Score
A	90	300	$600K	$6.7 M	81,111
B	80	250	$500K	$6.5 M	87,500
C	70	400	$800K	$6.3 M	101,428

Figure 1 - Example of Adjusted Score Method of Best Value Selection

The Lane Rental concept was developed to encourage contractors to minimize road user impacts during construction. The concept is intended to encourage contractors to schedule work such that traffic restrictions are minimized, both in terms of duration and number of lane closures. Application of the lane rental concept includes assessment of a rental fee for lane closures, the amount of which is stipulated in the contract documents. A lane rental fee is based on the estimated cost of delay or inconvenience to the traveling public during the rental period. The rental fee rates are applied in dollars per lane per time period. The time periods could be daily, hourly or fractions of an hour. The fee is assessed for the time that the contractor occupies or obstructs part of the roadway. The cumulative amounts are deducted from the contractor's monthly progress payments. Typically, the frequency or duration of lane closures is not indicated in the contract documents, only the rental cost per period. Neither is the contractor typically required to state the anticipated amount of closure. The lane rental cost does not factor directly into contractor selection, which is determined strictly on the lowest bid for the contract

Rental fee rates can vary with the number and type of lane closures and vary for different hours of the day or night. As an example, rush hour periods between 7:00 to 9:30 am and 3:30 to 6:30 pm might have an hourly rental fee of $1000 for closing one lane and an hourly rental rate of $500 during all other non-peak hours. Another scenario might include an hourly lane rental fee charged between the hours of 6:00 AM and 10:00 PM and no charge for overnight closures. The lane rental concept has value on projects that tend to significantly impact the traveling public such as interstate highways and arterials and other roads in urban environments. Lane rentals options can clearly affect a contractor's planning and execution of the work.

While perhaps not purely definable as an Innovative Contracting Methods or Procedures, true Value Engineering (VE) does require innovative thinking. VE is a proven methodology for improving value and quality. Value in this context can be conceptualized a (function + quality) ÷ cost. VE seeks the most cost-effective way to reliably accomplish a function that will meet the user's needs, desires, and expectations. The VE process is structured to enhance and optimize value, not "cheapen" the final product. VE considers economy in the total life cycle. The goal is to lower construction or life cycle cost without reducing quality or usefulness of a given system or component.

VE provides a systematic and rigorous framework for identifying unnecessary costs. Simultaneously, the approach assures compliance with quality, reliability, and other performance standards. Success of VE initiatives is dependent upon synergies gained through multidisciplinary or cross-functional teamwork. A VE study can be performed prior to the bid as part of the design review process or by the contractor under terms of the contract in which cost savings are shared by the owner and contractor. The questionnaire allowed respondents to indicate if VE was conducted during preconstruction or if a contractor-submitted Value Engineering Change Proposal (VECP) was implemented. The two choices are not mutually exclusive.

While not shown, these life cycle costs are certainly present and must be adequately addressed in all phases preceding startup. Life cycle costs beyond startup include maintenance, operations, rehabilitation, reconstruction, and de-commissioning. However, the focus of this study is on construction phase performance and not the facility life beyond commissioning. VE cannot only impact cost, but also the time associated with executing the construction phase.

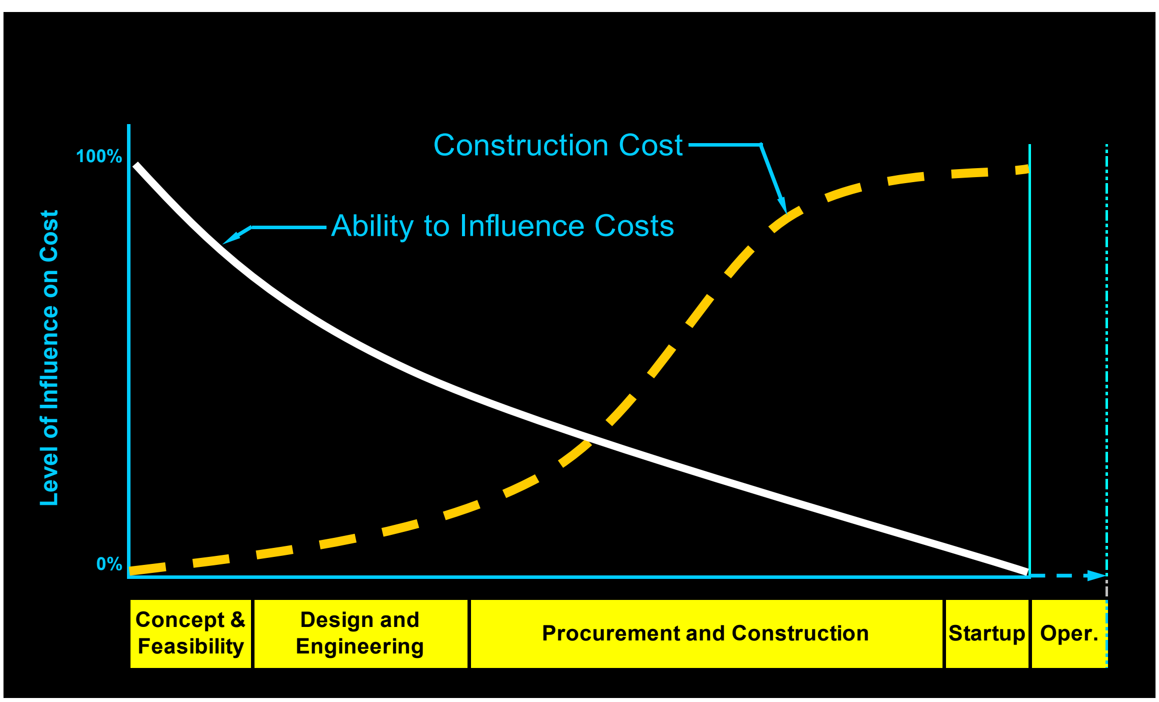


Figure 2 – - Cost-Influence Chart

The greatest potential to influence life cycle cost is during the pre-construction feasibility and design phases. The optimum time frame to perform an effective VE study falls within the pre-construction phases. The ability to affect or influence life cycle costs and other important performance characteristics such as time, quality, reliability, constructability, conflict avoidance, etc. diminishes over time as presented in Figure 2. The figure is a theoretical Cost-Influence chart originally conceived by the late Boyd Paulson of Stanford University that depicts diminishing ability to influence cost while construction and related expenditures increase over time (Barrie and Paulson 1984). This particular version of the chart does not show life cycle costs beyond startup or commissioning. Constructability studies also may not fit the current understanding of Innovative Contracting Methods or Procedures. However, constructability studies can significantly improve project performance in terms of cost, time, quality, safety, resource utilization, claims avoidance, etc. However, constructability studies are believed to be under utilized in bridge and highway engineering. Constructability reviews or studies are conducted during the pre-construction phases to identify obstacles or complications, which should be eliminated or mitigated ahead of the construction phase. The goal is to finalize design details, which translate into facilitated construction processes at the workface. Constructability studies are intended to avoid or at least reduce physical conflicts, which ultimately lead to relational conflicts, higher costs, and longer construction durations. An effective constructability study should result in contract documents that include details that can be built efficiently, productively, and safely in the field. The resulting contract document should be clear and explicit, with minimal errors or omissions, and contains all information required to complete the construction work with minimal delays, disruptions, and conflict.

“Constructability is the integration of construction knowledge and experience in the planning, design, procurement, construction, operation, maintenance, and decommissioning phases of a project consistent with overall project objectives (ASCE).” The Construction Industry Institute (CII) defines constructability as “the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives.” By these definitions, constructability includes the degree to which the design facilitates ease of construction, within the total requirements for the completed facility, whether building or infrastructure. Research conducted to date overwhelmingly demonstrates the potential for significant cost reduction and schedule improvement through the effective implementation of constructability principles and practices.

Formal Pre-construction Risk Assessment, much like formal constructability review, has the potential to significantly improve project performance but believed to be under utilized in bridge and highway engineering. Formal project risk assessment comes under the banner of Risk Management. While many fields and industries include risk management within their respective body of knowledge, this study considers the Project Management Institute (PMI) framework to be most relevant to bridge and highway engineering.

Risk management is defined as a proactive attempt to recognize and manage internal events and external threats that affect the likelihood of a project's success (PMI 2008).

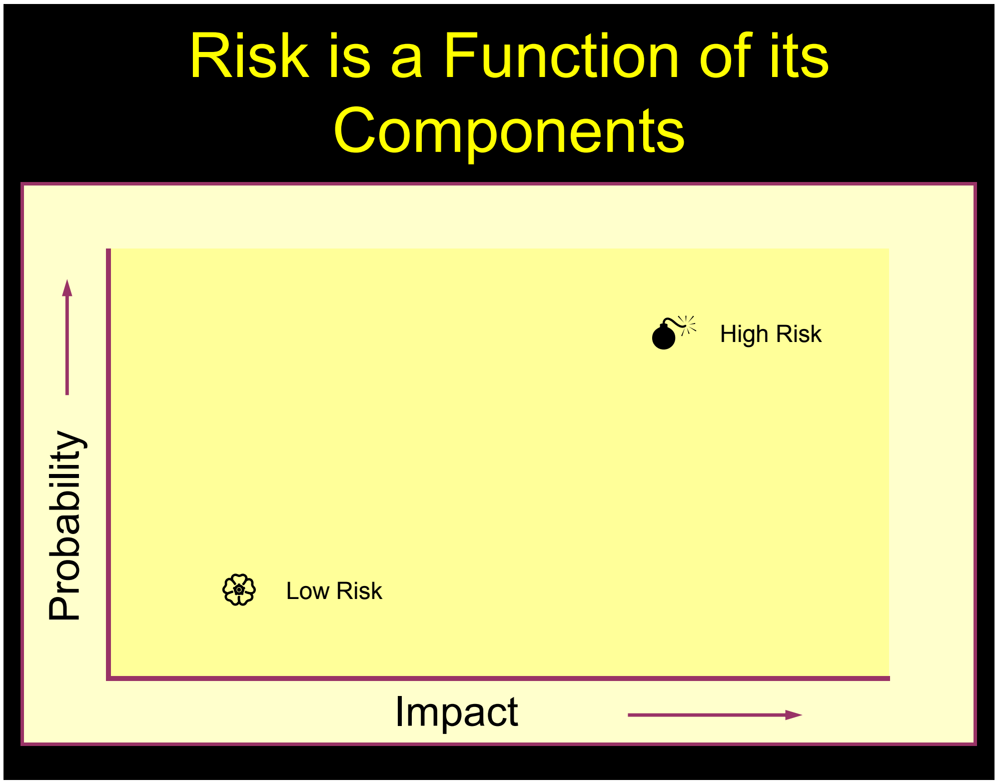


Figure 3 - Probability-Impact Chart

Risk is introduced through uncertainty and is a function of its components; probability or likelihood of an adverse occurrence and the impact of such an occurrence.

Pre-construction Risk Assessment affords an opportunity to proactively address project risks in the design phase, rather than reactive during construction, when the chance to avoid or otherwise mitigate the risk event is diminished. The advantages of reducing risk and negative consequences early improves the chances of reaching project performance objectives in terms of budget, schedule, quality, safety, liability, and general stakeholder satisfaction.

The next group of questions deals with the construction phase. The first question in the group sought to identify those charged with Construction Management and/or Inspection Services. The choices included consultant, owner, or owner lead w/consultant. The next question was in regard to Post-construction Review. The answer choices were none, informal, and formal review w/lessons-learned. This was followed by a question regarding Contemporary Management Paradigms.

3.3.7 Contemporary Management Paradigms

The choices of contemporary management paradigms included Integrated Project Delivery (IPD), Lean Principles, Six-Sigma, and Total Quality Management (TQM). These choices were not considered mutually exclusive. The management paradigms listed are not fully representative of systems or philosophies practiced in business and industry. They are however, prevalent is many of the stronger performing sectors of manufacturing. IPD is a formal collaborative effort intended to optimize project performance. It aligns people and systems across organizational boundaries. It further aligns business structures and practices into unified process for the purposes of increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction. "The IPD system is a process where all disciplines in a construction project work as one firm, creating faster delivery times, lower costs, no litigation and a more enjoyable process for the entire team – including the owner (http://www.ipdflorida.com/ 8/11/11, 9:30 PM)[12]. IPD in practice does incorporate many Lean principles and is closely linked to Lean construction on many levels.

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[12] IPD is also the name of a group of Orlando, FL. based companies that first utilized the IPD system and holds the trademark for the process.

Six Sigma is a business management methodology originally conceived by Motorola Corporation in 1986. Six Sigma is currently employed used in many sectors of industry to improve the quality of process outputs by identifying and removing the causes of defects and minimizing variability in manufacturing and business processes. While it was initially applied to manufacturing industries, its application has since spread to service industries. Six Sigma is based on statistical methods. A Six Sigma process produces products in which 99.99966% are expected to be free of defects. This translates into 3.4 defects per million. However, the full methodology transcends mere statistical analysis and seeks to establish a kind of unique infrastructure of people within the organization expert in Six Sigma methods. These experts are referred to as "Champions", "Master Lack Belts", "Black Belts", "Green Belts", etc. depending upon their position in the organization and requisite level of knowledge. There is significant of commonality among Six Sigma, Lean and many other quality initiatives. Six Sigma doctrine espouses continuous improvement and emphasizes reliability through reduction of process variation. Like the Toyota Production System and Lean practices in general, Six Sigma borrows from Deming's Plan-Do-Check-Act (PDCA) Cycle.

Six Sigma includes two formal methodologies based on PDCA, both comprised of five phases. DMAIC is intended to improve existing business process while DMADV is more design focus and is applied to projects intended to create products or processes. The latter is also referred to as DFSS; an acronym for "Design for Six Sigma". The five phases associated with DMAIC include:

1. ***D****efining* the problem and project goals
2. ***M****easuring* key pieces of the current process

3. ***A**nalyzing* the data to identify cause-and-effect relationships, ultimately identifying the root cause
4. ***I**mprove* or optimize the current process
5. ***C**ontrol* the processes going forward to avoid variation from target performance

The five phases associated with DMADV or DFSS include

1. ***D**efine* design objectives consistent with customer demands
2. ***M**easure* metrics that quantify various characteristics, especially those that are critical to quality
3. ***A**nalyze* in order to design alternative schemes
4. ***D**esign* the details
5. ***V**erify* and validate the design and hand off to the responsible production group

TQM or Total Quality Management is another management philosophy dedicated to continuous improvement in the quality of products and processes. The philosophy has been adopted by various segments of manufacturing internationally. The basic premise of TQM is that quality is the responsibility of everyone involved in the creation or consumption of the products or services offered by an organization. TQM involves not only management, but also the workforce and suppliers and includes customer involvement. Customer satisfaction is the driving objective and ultimate goal of TQM. Nine common TQM practices include cross-functional product design, process management, supplier quality management, customer involvement, information and feedback, committed leadership, strategic planning, cross-functional training, and employee involvement.

In a TQM effort, all members of an organization participate in improving processes, products, services and the culture in which they work.

TQM is heavily based upon the teachings of quality gurus Philip B. Crosby, W. Edwards Deming, Armand V. Feigenbaum, Kaoru Ishikawa and Joseph M. Juran. Deming's 14 Points of Management applied in TQM include:

1. Create constancy of purpose for improving products and services
2. Adopt the new philosophy
3. Cease dependence on inspection to achieve quality
4. End the practice of awarding business on price alone; instead, minimize total cost by working with a single supplier
5. Improve constantly and forever every process for planning, production and service
6. Institute training on the job
7. Adopt and institute leadership
8. Drive out fear
9. Break down barriers between staff or functional areas
10. Eliminate slogans, exhortations and targets for the workforce
11. Eliminate numerical quotas for the workforce and numerical goals for management
12. Remove barriers that rob people of pride of workmanship, and eliminate the annual rating or merit system

13. Institute a vigorous program of education and self-improvement for everyone
14. Put everybody in the company to work accomplishing the transformation

2.3.8 Expediting Strategies

Expediting Strategies include techniques intended to reduce the duration of the construction phase. The four expediting strategies considered in this study include Precasting, Off-site Prefab, On-site Prefab, and Hyper-Build. These and other expediting strategies continue to be the subject of research and development by various transportation agencies, manufactures and suppliers, and academia. The FHWA and AASHTO's Technology Implementation Group (TIG) (AASHTO) jointly administer the Accelerated Construction Technology Transfer (ACTT) program. Precasting concrete structural elements for expedited installation in the field is not new. The introduction of pre-stressing techniques in the 1950's substantially expanded the types, sizes, and configuration of precast elements. Precast concrete elements are commonly installed rather then using cast-in-place methods. These elements typically include drainage structures such as inlets, manholes, end walls, and head walls; electrical junction boxes and buried telephone vaults; pipe and culverts; curb and barrier wall, and sound wall systems. Precast mechanically stabilized earth wall panels are often used in place of conventional abutment breast walls, wing walls, and other types of retaining walls.

Precast concrete elements have been common in bridge construction in the United States for quite some time. What is new is the scale and the creativity in which precast concrete techniques are being applied. Full-depth precast deck panel systems are gaining acceptance across North America (Badie 2006). Precast deck panel systems have the potential of significantly accelerating bridge construction or reconstruction. Segmental bridge construction techniques are widely accepted and especially well suited for long spans. A segmental bridge is built in short sections or "segments", progressing one piece at a time. While cast-in-place segments are sometimes used, the much more common approach is to employ on-site or off-site precasting methods.

Similar to precast concrete elements, use of prefabricated steel or other metal elements is not new. Again, what is new is the scale and creativity to which prefabrication is applied. Off-site fabrication of structural elements such as floor beams and stringers, girders, and truss members dates back to the era of iron bridges. Today, larger components are being shop fabricated and shipped to the site for field installation. Hybrid designs, which incorporate high strength steel and composite materials result in lighter components that can be shipped and erected using conventional methods. The pre-assembly of these larger units can substantially reduce construction duration and minimize the disruption of existing traffic flows. Prefabrication is not limited to the shop or remote yard, but can also be performed within the project limits.

On-site prefabrication employs many of the same techniques and applications associated with shop fabrication. The major advantage of on-site prefabrication is the reduction of shipping costs and time. Moreover, larger elements or components can be fabricated in the field without concerns of exceeding allowable shipping weights or sizes. Items that are prefabricated in the shop will be limited to permit loads, cross section clearances imposed by bridges and roadways, and turning radii along the shipping route. The disadvantages of on-site prefabrication include the need to setup tooling such as jigs, fixtures, and tables, which are generally available in the shop. Field conditions cannot always economically mimic shop conditions, and there are some elements that are better fabricated off-site. Also, space may be at a premium in the field and there may not be sufficient area within the project limits for prefabrication operations. However in this author's opinion, anytime that a construction site can be made to resemble and flow like a Lean factory floor is an opportunity to achieve greater efficiency and productivity at reduced construction duration.

Under the direction of former Commissioner, Jack Lettiere, NJDOT instituted a concept known as "HyperBuild". The HyperBuild approach came about after Hurricane Ivan washed out a bridge on I-70 near the Jersey shore (AASHTO 2005). The Department, its consultants and contractors were able to install a temporary structure in place within three days of the washout and complete the final replacement in 110 days. Commissioner Lettiere and his staff posed the question "if we could do that once, why can't we do this time and time again", hence the birth of HyperBuild. HyperBuild is defined as a philosophy, not necessarily a series of steps. It is a philosophy that challenges designers and constructors to seek out the most the innovative and efficient ways to produce a project in the least amount of time. It mandates consideration of new products, tools, and techniques. Minimizing the impact on the traveling public and the surrounding community joins essential criteria such safety and capacity as the driving design factors for a HyperBuild project. While minimizing construction time is the primary focus, HyperBuild design and construction practices are intended to allow traffic to flow with minimal disruption on the existing roadways during the construction phase.

Figure 4 - Nighttime installation of a railroad bridge over I-76, just west of Philadelphia, PA.

HyperBuild and all of the other aforementioned practices present opportunities to reduce overall construction phase time.

2.3.9 Project Outcomes Data

The section that follows in the questionnaire deals with project outcomes and apparent reasons or explanations for those results. The first question along these lines dealt with post-award cost growth and read, “Which of the following caused the final cost to exceed the original contract amount?” The respondents were instructed to check all that apply. The five given choices included design change/plan revision(s), adjusted final quantities (net increase), differing site conditions, contractor claim or compensable delay, and one or more indicated constraints. A sixth choice included “Other” with the request that the respondent please explain below.

The next question addressed time escalation and read “Which of the following caused the final project duration to exceed the original contract duration or completion date?” Again, the respondents were requested to check all that applied. As in the case with post-award cost growth, multiple factors can simultaneously contribute towards construction time escalation. However, the given choices included sixteen factors including the choice of “Other”, again with the request to explain below. The choices provided included owner requested design change, differing or unforeseen site conditions, design errors or omissions, poor constructability, utility conflict, right-of-way conflict, poor contractor performance, lack of timely resolution of problems, weather and seasonal impacts, unrealistic original contract duration, interference from outside agencies, lack of commitment, adjusted final quantities, Force Majeure (with the request to explain below), and one or more indicated constraints.

An open-ended question followed these two questions, in which the respondents were asked to provide a brief summary of special or extraordinary circumstances that contributed toward post-award cost or time growth. These three questions were followed by a series of somewhat subjective questions concerning project input and outputs.

2.3.10 Key Performance Indicators

The final section of the questionnaire found on pages 3 and 4 includes a series of questions intended to reveal the quality of project inputs and outputs, hereafter referred to as Key Performance Indicators (KPIs). Some of the input was gauged in terms of attitudes. Responses to these questions are stated as semantic differentials on a 7-point scale, with the exception of two questions. The first question asked "How ambitious was the original construction contract duration?" with 1 being Not Very and 7 being Very. The next question was not based on a semantic differential, but rather a pure ranking. The respondents were asked to rank the importance of project outcomes in terms of the triple constraints of cost, quality, and time with 1 being the highest priority and 3 being the lowest.

The respondents were asked to answer the question that followed if the final project duration exceeded the original contract duration. The question read "If not for the stated occurrences/situations, what is the likelihood that the contractor would have finished the project within the original contract duration?" with 1 being Not Very and 7 being Very likely.

The next question concerned the comparative complexity of the project in question. A declarative statement preceded the question in order to define "complexity" in terms of highway projects[13]. The statement read "Complexity in highway project construction is a function of: 1) the number and level of physical constraints, i.e.: space, traffic, utilities, wetlands, waterways, railroads, etc.; 2) interdependencies among activities and/or resources; 3) staging (sequence) or phasing of work; 4) contractual and/or other legal constraints; 5) socio-political influence; 6) complexity of details; 7) degree to which work is not linear or repetitive; 8) uncertainty requiring adaptability. Moreover, an increase in the level of complexity requires a corresponding increase in the intensity of management effort to ensure successful project outcomes." The ensuing question read "Given the stated criteria, how complex was this project in comparison to the typical project?" with 1 being Not Very and 7 being Very complex. Complexity is not viewed as an input, but rather as a state or condition that is a result of the interdependencies of the inputs, constraints, and conditions listed in the accompanying statement.

The next questions return to evaluating inputs. The next in line reads "Compared to other projects, what was the general quality and effectiveness of the contractor's schedule?" with 1 being poor and 7 being excellent. The question sought to determine the efficacy of the schedule generated by the contractor. In order for a construction schedule to be effective, it must first be reflective of the constructor's true work plan. It must be comprehensive and logically valid. Quality measures would include the completeness of the schedule in terms of activities, precision of sequence and logical

[13] As noted previously in this chapter, the statement was validated by several highway engineering professionals. Of the 50 polled, 39 engineers with an average of 33 years of experience in the highway industry responded. 37 of the 39 responded positively. This translates into a 76% response rate with 95% of the respondents validating the complexity criteria.

relationships, and the accuracy of the durations. Obviously, the schedule must be based on a sound work plan; otherwise, it's garbage in, garbage out (GIGO).

A closely related question asked "Did the contractor's schedule appear to be produced merely to satisfy a specification requirement or an attempt to provide an effective tool to manage time, resources, and constraints?" with 1 being a requirement satisfaction and 7 being an effective tool. Most highway projects include the contract requirement that the contractor prepare and submit an original schedule, regular updates, and a final as-built schedule. Some schedule specifications are quite rigorous, requiring a WBS, several levels of activity coding, and resource loading. Often, issuance of a notice-to-proceed (NTP) is dependent upon the owner's review and approval of the contractor's original schedule. Release of monthly progress payments is often tied to review and approval of schedule updates submitted by the contractor. Some contractors or their project management personnel when faced with these contract obligations will produce a schedule merely to satisfy the contract requirements. A schedule that is produced merely to satisfy a requirement is faulty and will not serve as an effective time management tool. In such a schedule, there is little alignment with the contractor's work plan. The schedule is not a product or output of the planning process. The corollary is that the planning process is undercut. Schedule preparation does not require or promote good planning. Consequently, it is ineffective in guiding execution of construction operations.

No matter how strict or prescriptive the specification, the owner does not dictate the constructor's work plan. Schedule specifications, with few exceptions, do not dictate the constructor's means and methods, sequence, logic, or durations[14]. It is the

[14] Contract plans and specifications may include some general requirements regarding sequence (i.e.: phasing, staging, or milestones) in response to MOT, seasonal, or regulatory requirements. Such specifications however, do not prescribe specific activities or their sequence and logical relationships.

constructor's sole responsibility to craft a viable work plan based on their understanding of the work at hand and to reflect that plan in the schedule. An effective work plan, and therefore an effective schedule must adequately address all aspects of the work including contract requirements, constraints, resources, and interdependencies.

Questions regarding relationships were also included in this section. Relational interaction is considered an input since projects are considered social constructs. The first relational question asked "Compared to a typical project, the working relationship and level of trust between the owner and contractor on this contract was:" with 1 being much worse and 7 being much better. Research on projects in other industries and sectors has demonstrated the positive correlation between trust and project performance <citation>. A related question asked whether "there were claims filed by the contractor against the owner?" requiring a discrete yes or no answer. This was followed by the open ended question "If so, how many?" after which the question "Were any claims for delay or disruption?" was posed. Filing of claims is an indication of a poor owner-contractor relationship. Parties operating with a high level of mutual trust and respect generally do not sue one another.

Poor relationships coincide with weak communications. Lack of mutual trust translates into lack of open and honest dialogue. Such conditions generally do not promote timely resolution of problems. Nearly as crippling as poor owner-contractor communications are poor intra-agency communications. The relevant question asked "Compared to other projects, the level of intra-agency communication within the DOT/SHA on this project was:" with 1 being much worse and 7 being much better[15].

[15] The order of the questions noted here does not precisely correspond with the order listed on the questionnaire. The slight deviation promotes meaningful grouping and corresponding explanations.

While responses to this question do not gauge the mood within the agency, it does measure the effectiveness of the internal lines of communication. Prompt responses to RFIs (requests for information) and early resolution of problems are essential to smooth, timely project execution and avoidance of delays and disruptions.

Finally, three questions were posed which dealt with the quality of the plans and other contract documents. The first of these asked, "How comprehensive and accurate were the plans and other contract documents compared to the typical project?" with 1 being much worse and 7 being much better. The next asked "How constructable were the plans and details for this contract compared to the typical project?" again with1 being much worse and 7 being much better. The final question regarding contract documents was not project-specific, but had much broader industry implications. The question was "In general, do you believe that the quality of design plans is increasing or decreasing?" with 1 indicating decreasing and 7 indicating increasing. The quality and constructability of bridge and/or roadway plans are vital to project success. The comprehensiveness, clarity, and accuracy of all contract documents directly affect the conduct of the work and timely execution thereof.

Table 1 -- Excel output of sample size, n, calculation

Sample Size For Mean TPI	
Data	
Population Standard Deviation	0.23
Sampling Error	0.05
Confidence Level	90%
Intermediate Calculations	
Z Value	-1.6449
Calculated Sample Size	57.25
Result	
Sample Size Needed	**58**

2.4 Survey Sample Size

The required sample size necessary to assure statistical significance of the HPP Study was computed using the results of the pilot study. The calculation was performed to find the minimum sample size to determine the Mean TPI. The formula used to find the minimum sample size, **n**, is the product off the $Z_{\alpha/2}$ value squared and the standard deviation, σ, squared, divided by the square of the sampling error, e. $Z_{\alpha/2}$ is the critical value from the standardized normal distribution for an acceptable confidence level. A 90% confidence level was deemed appropriate for the HPP Study yielding a $Z_{\alpha/2}$ of 1.6449. The sampling error, e, considered acceptable was 0.05. The standard deviation of the Mean TPI from the pilot study was used where σ equals 0.23. Given these factors, the resulting minimum sample size, **n,** is 58. Table 1 shows the Excel solution.

2.5 IRB Review and Approval

Prior to the pilot study, the author sought and obtained Institutional Review Board (IRB) approval. This first required online training in human subjects research. Training Certificate No. 22433, 7/2/2009 is included in the appendix of this thesis. The submission process required submission of a research proposal with detailed description of the proposed protocol. The proposed protocol was reviewed and approved as Exempt research (45 CFR 46, 101(b) (2)). The approved study is Project No. 1043276, Protocol No.: 18451, Action No.: 52606, Detail No: 257478 dated 8/14/2009. A copy of the IRB Approval Notice (Exempt) is included in the appendix of this thesis.

2.6 Pilot Study Data Collection

Pilot study questionnaires were distributed upon receipt of IRB approval. Twenty (20) pilot study questionnaires were distributed via email to engineers responsible for construction at DelDOT in September 2009. Collection of completed questionnaires ran through November 2009. A total of seven (7) completed questionnaires were received, providing the base data for the pilot study. This yields a survey response rate of 35%. These pilot study questionnaires were later converted to the final questionnaire format. The process required that additional information and validation be obtained from the original respondents. This additional information gathering and validation was conducted via emails and telephone conversations.

2.7 Final Survey Distribution

Distribution of the paper questionnaire was initially accomplished via First Class Mail through the United States Postal Service (USPS) sent to various parties within the target transportation agencies. The packages included a cover letter, the 4-page questionnaire, an overview of the HPP Study, and instructions for respondents. A sample of each of these documents is included in the appendix of this thesis. The package also included #10 size return envelops addressed to the author at his Drexel University mailing address. Postage was not included on the return envelopes. The cover letters were personalized with formal salutations. Overviews were tailored to the individual agencies, e.g.: “The study is conducted from the owner’s (DOT’s) perspective and includes agencies from the Northeast and Mid-Atlantic Regions, including NYSDOT.”

The initial mailings began in July 2010. The web-based questionnaire was launched in SurveyMonkey in March 2011. Several additional rounds of mailings were conducted after the launch of the SurveyMonkey questionnaire. However, these packages were amended to include a link to the SurveyMonkey webpage. The potential respondents were encouraged to use the link to complete the web version, but were given the opportunity to complete and return the paper questionnaire. Post cards containing the SurveyMonkey link requesting participation in the study were distributed beginning in

June 2011. Finally, direct email messages with the link were sent to additional prospective participants. The overview and instructions to respondents were included as attachments to the emails. The final round of mailings and email distributions was made in August 2011. Subsequently, the number of completed questionnaires received satisfied the minimum sample size. The only correspondence sent after this point was thank you notes. Distributions were recorded using an Excel spreadsheet.

2.7.1 Recipients

Initial requests for participation were made to the chief research officers of the various highway agencies, typically the Director of Research or similarly titled individuals. The initial response was very weak. The next group included the District Engineers or District Executives. Again, the response was limited. The strategy shifted to a top-down approach in which the Secretaries, Commissioners, Deputy Secretaries, and other high level officials within the various State DOTs were contacted. The mailings were supported by phone calls and in some cases, direct face-to-face meetings. Intermediaries helped promote participation in the study. While the top-down approach was somewhat more effective, the level of responses was still insufficient. District Engineers/Executives were again contacted along with District Construction Engineers, Assistant Construction Engineers, and Area Engineers. This effort was followed by requests made to directly to Resident Engineers via USPS and email. Reaching out directly to the targeted respondents eventually proved to be effective.

CHAPTER 3: CONTEMPORARY APPROACHES TO CONSTRUCTION PLANNING & SCHEDULING

3.1 Introduction

This chapter provides an overview of contemporary approaches to planning and scheduling of construction projects. It is intended to provide the background information necessary to understand common practices including methodologies, processes, and philosophies prevalent in the industry. Certain knowledge and understanding regarding planning and scheduling are essential for fully comprehending the analysis and potential interventions that follow. While the information presented is biased toward transportation infrastructure projects, most topics covered have strong relevance to work in other construction industry divisions and sectors. For that matter, there is a great deal of applicability to project-driven environments beyond construction.

The author has attempted to present best practices related to construction planning and scheduling. However, even the "best practices" often fail to achieve the desired results. For the most part, this chapter provides limited critique. Critique of the prevailing project management paradigm is presented in some depth later in this thesis. This chapter provides substantial but not exhaustive coverage of approaches and techniques associated with project planning and scheduling. The Critical Path Method or CPM Scheduling, and more specifically the Precedence Diagramming Method (PDM) receives the greatest coverage of the scheduling techniques presented in this chapter.

Again, the treatment is substantial, but not exhaustive. CPM variants and other alternative scheduling techniques are covered in the chapter that follows.

The chapter begins by making the case for formal time management of construction projects. It states the necessity for and the practical benefits of time management. The time management process is then framed within the context of the project, which leads to an introduction to planning. The section includes descriptions of various approaches to planning as well as discussion of the social dynamics and organizational psychology aspects, which are often neglected topics. An introduction to contemporary planning tools such as the Work Breakdown Structure (WBS), Responsibility Matrix (RM), and Organizational Breakdown Structure (OBS) are then presented. At this point, the discussion focus transitions from planning to scheduling. However, the topic of planning and the importance of effective planning is a common theme throughout this chapter and for that matter, throughout the entire thesis.

Coverage of scheduling begins with an historical overview followed by an introduction to the basics of CPM, preparation of the network, formulation of logical relationships, and a description of the major subparts of a comprehensive construction schedule. The discussion continues with practical approaches to drafting the rough diagram including a method popular in building construction referred to as the Gilbane Card Trick. The next two sections address estimating and managing durations. Again, the discussion not only covers the mechanics of calculating proposed activity durations, but also addresses the social and psychological issues surrounding development and management of those durations. The value of maintaining a viable schedule and the mechanics necessary to accurately model the project work plan is described in the section titled "Monitoring, Updating, and Revising Schedules." Sections follow this on the development and use of short interval and milestone or goal-oriented schedules. CPM enhancements are then introduced. The enhancements described are those largely facilitated by personal computers together with commercial software. This includes the database functions of organizing, storing, and retrieving schedule data. The section also addresses activity coding, multiple calendars, artificial constraints, and resource and cost loading. While various scheduling software solutions are mentioned repeatedly throughout this chapter, there is no attempt to provide instruction in the use of that software. A critique of commercial scheduling software and its' application is addressed later in this thesis. The chapter concludes with sections on Earned Value Analysis (EVA) and Earned Schedule Analysis (ESA) under the umbrella of Earned Value Management.

3.2 Necessity for Time Management

The necessity for time management of construction is rather obvious. The old adage "Time is money" holds true. Time in fact is money to owners, builders, and users of the built environment. There are several concerns with time from the owner's perspective which include:

- lost revenue -- not receiving return on investment
- cash flow crunch
- potential alienation and loss of clients/tenants
- extended interest payments
- tax considerations
- negative marketing impacts

- From the users perspective:
- financial implications similar to owners
- delays in upgrading facilities means operating at below optimum efficiency -- higher cost
- delays in constructing or rehabilitating infrastructure negatively affects businesses and the public at-large. While there are considerable quantifiable cost impacts, there can be significant quality of life issues associated with denial of timely service. These impacts were emphasized in the introductory chapter of this thesis.

From the constructor's perspective:

- liquidated damages (negative)
- incentive or bonus (positive)/disincentive or penalty (negative)
- delays result in extended overhead costs and other liabilities
- delays also put a crunch on critical cash flow
- extending durations beyond the acceptable time frame limits the contractor's bonding capacity and ability to bid more work
- inefficient time management results in higher labor and equipment costs
- a reputation for late completions is bad for business, especially in negotiated work or selection through a preferred bidders list (typically limited to the private sector)

3.3 Practical Benefits of Time Management

The time management process produces practical tools, i.e. various forms and levels of schedules, which enable the project team to plan, track, and manage activities. There are also a number of incidental benefits derived through the scheduling process. Having a formal planning and scheduling process in place requires managers to think the project through prior starting the work. It provides a structured method to planning and executing the work rather than a crude, seat-of-the-pants approach. A formal schedule is a means of communicating the work plan to others.

In times past, the only parties privy to or concerned with the project schedule were the owner, the contractor, and perhaps the designer. The reality of today's construction projects is that there is a multitude of stakeholders involved in the process, most of whom have at least some interest in the schedule. The range of stakeholders in contemporary projects extends beyond the supply chain to include regulators, lenders and stockholders, and the pubic at-large. Not that these stakeholders did not previously exist, most did but their influence on the design and construction process was limited or even nil. A publishable schedule provides a means to communicate the work plan to the various concerned stakeholders.

Formal planning and scheduling induces early risk management by identifying problems before they arise. Risks associated with project execution can be identified and either avoided or mitigated prior to being encountered in the field. Master schedules prepared sufficiently ahead of construction yield the benefit of identifying long-lead fabricated items which otherwise neglected could severely impact progress and timely completion.

Preconstruction schedule preparation enables assessment and projection of resource requirements over the life of the project. With enterprise-based scheduling such as that afforded by Primavera P6 software, a constructor can assess and allot resources (at least theoretically) across the entire organization. Some attempt to utilize a construction schedule to manage resources across the entire project team. While the efficacy of controlling resources via the construction schedule may be limited, the value of identifying resource requirements early is undeniable.

Cost-loaded schedules enable affected parties to project cash flows. Certainly the accuracy of cash flow forecasts is dependent on much more than merely the accuracy of the schedule. Obviously factors such as actual costs, actual progress, change orders, varying interest rates, lag time between billing and payment, markup, and retainage amounts all affect cash flow. Most would argue that even tenuous cash flow forecasts are better than none at all. Cost loading schedules also enables managers to perform Earned Value Analysis (EVA). An explanation of Earned Value Analysis follows in a later section of this chapter. A critique of EVA is included in a discussion of the limitations and failures of contemporary project management practices. In spite of the shortcomings that will be discussed, EVA does yield metrics by which performance can be assessed. This would not be possible without a formal project schedule.

Contemporary scheduling techniques and the supporting software provide managers with the tools necessary to analyze the impact of changes to the scope before or after the fact. Preparing "what-if" or mockup schedules aids in the decision making process and informs the stakeholders of the impact of proposed changes. Analysis of the schedule after the fact is often performed to support or disprove a claim for delay or disruption.

CPM scheduling has become an essential component of delay claims management (Yates and Epstein 2006). An entire sub industry to construction has emerged to address time-based disputes. Some would say that this situation has been fueled by the "lawyerization" of the engineering and construction industry (Owens and Ariaratnam 2007). Claims for delay and/or disruption represent a large percentage of all construction related disputes. While time-related disputes in construction can be traced back to time immemorial, it is the advent and proliferation of network scheduling techniques that provided the evidentiary platform for these claims (Wickwire et al 1989, Sweet and Schneier 2004). The schedule is used as primary evidence to demonstrate or refute entitlement and the associated damages resulting from delay or disruption. Forensic Schedule Analysis (FSA) includes several different methodologies for analyzing construction delays, the discussion of which is beyond the scope of this dissertation.

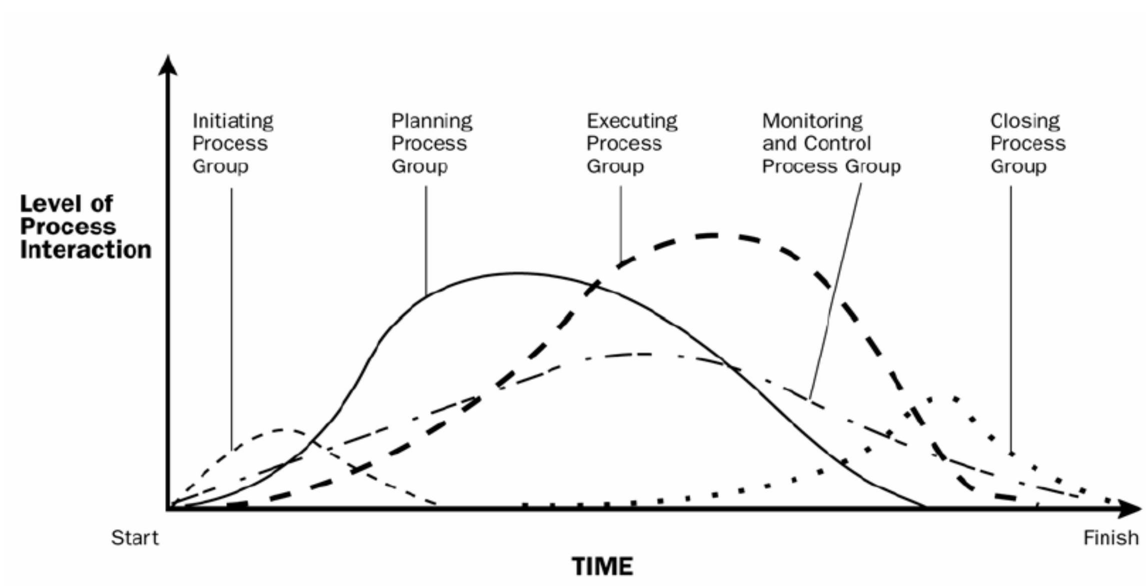

Figure 5 - Five Process Groups
Adapted from the PMBOK 2008

2.1

3.4 Time Management Process

In this thesis, time management, and specifically scheduling are referred to within the context of the "project". A project represents a unique set of activities that must take place to produce a unique product. The success of a project can be judged in terms of meeting the criteria of cost, time, performance (scope, quality, and function), safety, resource allocation, and stakeholder satisfaction (Primavera 2009). Time management can affect project outcomes in terms of the stated criteria. The contemporary view of the time management process can be roughly segregated into the four phases of planning, scheduling, monitoring, and controlling.[16] This loosely coincides with the Project Management Institute's (PMI) five process groups of Initiating, Planning, Executing, Controlling and Monitoring, and Closing (PMI 2008). While there is a traceable linear progression of phases, the activity associated with each process is variable along the project timeline with substantial overlapping of phases as depicted in Figure 3.

3.5 Planning

In terms of time management, planning is the necessary forerunner to scheduling and includes defining work tasks, determining general sequence, establishing the means and methods of execution, assigning responsibility, developing the project organization, and determining the chain of communication. The planning process considers the project and answers the questions *what, where, why,* and *who.* The scheduling process determines *when*. Planning involves information gathering, learning, and decision-making and

[16] References to the contemporary paradigm of time management and more broadly, project management are based on the prevailing understanding articulated by organizations such as the Project Management Institute (PMI) and found widely in texts dealing with the subject.

requires knowledge and creativity. Interrelationships and interdependencies among activities and project team members are identified or created and eventually (hopefully) strengthened.

Traditional design-bid-build delivery in the highway industry generally does not afford much time for preconstruction planning. Preconstruction planning usually must occur quickly after bid opening; typically in the range of 25 days to 3 months. Apparent low bidders on highway projects often refrain from serious planning efforts until formal award of the contract. Waiting for the formal award hedges the contractor's risk of wasted effort and expense should for some reason the owner not award the contract to the apparent low bidder[17]. However as is often the case, reduction of one risk can lead to the introduction or increase of other risks. In the case of deferment until actual award, the amount of time available for reconstruction planning is diminished. Plans made in haste are almost always faulty and often suffer from errors and omissions. Such hastily produced plans fail to fully identify impending risks and may include means and methods that unnecessarily introduce epistemic risks (McCann 1998).

The team approach to planning is considered a "best practice" in various treatises on the subject. Various authors and organizations suggest that construction planning is best done in teams by the people responsible for executing the work (Newitt 2009, Rosenau and Githens 2005). The author of this thesis has employed the team approach to planning numerous bridge and highway projects, as well as other types of construction work. He is completely convinced that the project team should plan all but the smallest

[17] Reasons that a public owner may not award a contract to the apparent low bidder might include the contractor's bid proposal being deemed irregular, a bid amount substantially higher than the Engineer's estimate, or a sudden problem with funding.

and simplest projects. While he holds fast to this belief, his observations indicate that this approach unfortunately is not the norm. Planning is often conducted in isolation by either the project manager, scheduler, or in some cases, the superintendent. Planning in isolation disregards the benefits of synergy in which the whole is greater than the sum of its parts. The capacity to brainstorm can only be found in a group or team of collaborators, not within a single individual. “No man is an island” John Donne, 1624 (Donne, 1624)… “he’s a peninsula” Jefferson Airplane, 1967 (Jefferson Airplane, 1967).

Modern management theory emphasizes team-oriented approach to business. Moreover, successful projects require a mind-set of teamwork geared for problem solving through learning. In addition to the synergistic generation of ideas, identification of risks, and comprehensive planning, the team approach confers automatic ownership of the plans to the project team. Ownership of the schedule by those charged with execution of the work provides a powerful psychological advantage that is arguably as important as the practical benefits of innovative idea generation, etc. An initial meeting for construction planning of a highway project may include the contractor’s project estimator, general superintendent, scheduler, superintendent; usually led by the project manager. The subsequent in-depth planning sessions will likely exclude the estimator, but possibly include key foremen and perhaps key subcontractor representatives. Input from subcontractors, fabricators, suppliers, and utility companies during the planning phase are vital.

Initial planning activities include learning via document review and field view. Contract documents which must be reviewed and understood by the team include design drawings (a.k.a. “the plans” or “the blueprints”), standard and supplemental specifications, special provisions, general conditions or provisions, general notices, agreement form, advertisement for bids, instruction to bidders, notice of award, and notice to proceed. Other documents that must be reviewed and understood (if applicable and/or available) include geotechnical reports, environmental assessments or environmental impact studies, all applicable permits (environmental or otherwise), memoranda of agreement or understanding with any project stakeholder, transcripts of pre-bid meetings, and minutes of the preconstruction meeting. The project team should also review all available shop drawings, catalog cuts, and other relevant documentation generally submitted to the DOT[18]. Review of the cost estimate may facilitate learning, thereby quickening the team's understanding of the scope of work.

Planning cannot effectively be performed strictly in an office or trailer. The team should visit the proposed site to really understand the lay-of-the-land so to speak. While 3D models, video, and photographs (including aerial) can aid in understanding the scope, nothing can substitute for the team being together at the site. A field view enables the team to experience the true environment in which the work must be conducted. The team can see the existing topography as well as the physical constraints imposed by the natural and built environment. The team is better positioned to identify impending risks associated with the site and its surrounding environs. Standing at the site with plans in hand can derive a more vivid mental picture. Such visualization is further enhanced through delineation of the essential lines and grades. Having surveyors complete at least a rough stakeout of the proposed construction prior to the team's visit to the site is highly

[18] The author has observed several instances where those charged with executing the work unfortunately did not possess or had not even seen approved submittals such as shop drawings. Many of these instances have resulted in delays, reduced quality, rework, and even near catastrophe.

recommended. A mark-out of all underground utilities within and adjacent to the site should also be completed prior to the team's visit. The necessity of the field view cannot be overemphasized. Again, it is critical that this includes the team and not merely an individual or two, or individuals visiting at different times. It is synergistic learning that best translates into competent planning. The importance of continually "going to the gemba" will be presented in sections addressing Lean philosophy.

Once the team has developed an initial understanding of the project scope, risks, and opportunities, they begin to craft the plan. Like planning and scheduling, learning is an iterative process. The team will continue to learn and understand more about the project through the course of planning and scheduling. The truth of the matter is that the team really will not understand the true nature and requirements of the work until the work is well under way. An experienced team realizes that the plans they prepare are not certain. In today's conventional construction environment, project plans are always subject to change. One of the dominant drivers of this thesis is to make plans more reliable.

Having gained the initial understanding of the project, the team can begin answering the 4 "*Ws*". The team formally proceeds to answer the questions of *what, where, why, and who*. *What* exactly are the specified deliverables? *What* should they look like when completed? *What* actions or activities are necessary to deliver the constructed product? *What* are the preferred means and methods? *What* sequence should be used? *What* significant risks are involved with the work and how will they be addressed? *Where* will the deliverables be situated? *Where* are the required utilities, ingress/egress, and conflict points? *Where* should material be stored? *Where* should the field office and other temporary facilities be placed? *Where* should cranes and other heavy equipment be staged? *Why* are the deliverables arranged in a specific alignment? *Why* do the plans require that a portion of the work be executed in a particular order? *Who* will do the work; in-house crews, subcontractors, or a combination of the two? *Who* or which subcontractors, suppliers, consultants, and fabricators will do the work?[19]

A variety of planning tools are available to facilitate learning and model the project. Some of these tools are discussed in the sections that follow and include the work breakdown structure, organization breakdown structure, and responsibility matrix. While several other project management tools are available for modeling and managing infrastructure projects, the discussion in this thesis is limited to those listed since they do provide input into the schedule.

3.5.1 Work Breakdown Structure

There is a number of conventional project management tools typically employed to depict the work plan, starting with the Work Breakdown Structure (WBS). A comprehensive WBS can provide input necessary to develop other tools including the project budget and cost control plan, schedule, responsibility matrix, and risk management plan as shown in Figure 6. The

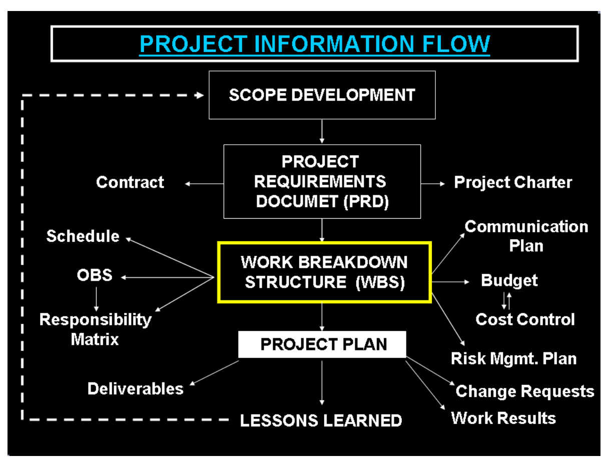

Figure 6 - Project Information Flow

[19] This is frequently a senior management a decision and unfortunately is often based on the lowest price. As will be discussed later in this thesis, the lowest price is not always the best value for the procurer.

WBS is a hierarchical outline or map that identifies the products and work elements involved in a project. It is arranged in a family tree division of components that defines he relationship of the final deliverable, i.e.: the project, to its sub-deliverables, and in turn, their relationships to work packages. It is well suited for constructed facilities that have tangible outcomes rather than process-oriented projects. The WBS is a decomposition of the project layered in levels of indenture. The elements on one level

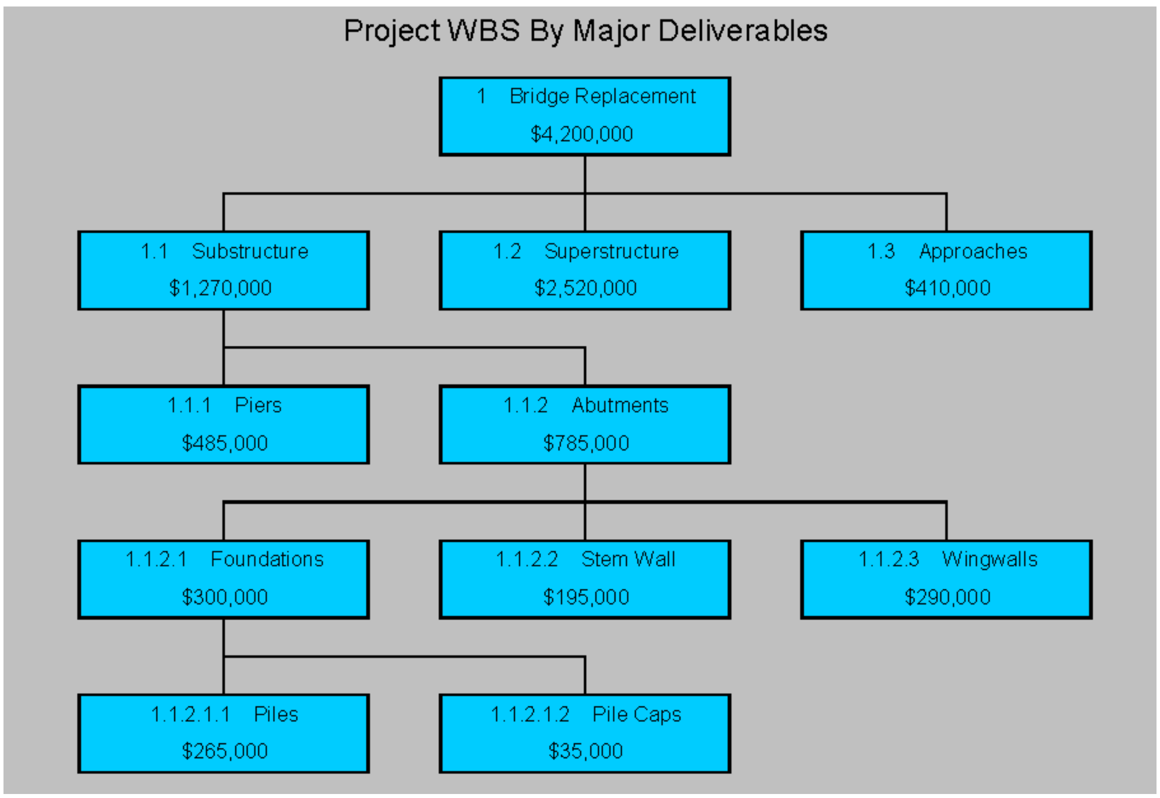

Figure 7 – WBS Example: Bridge Replacement Project

are decomposed or exploded into greater detail on each succeeding hierarchical level. Each descending level presents the previous level's parts in increasing detail (Patrick 2004, PMBOK 2004). The levels of indenture for a small to mid-size construction project could be arranged with the Project level on the top line, followed by the Phase or Systems level, then by the Cost Account level, Work Package level, and Task or Activity level. Naming the level is not important. Correctly breaking down the elements from level to level is essential.

A comprehensive WBS utilizes an identification system to compliment the descriptors for each element. This is particularly useful for budgeting and cost control coding. Identifiers can utilize numeric, alphabetic, or any alphanumeric combination. WBS ID coding systems can vary from project to project or organization to organization. The identifiers do however; follow an indenture structure that expands from level to level. The simple WBS shown in Figure 7 depicts a portion of a bridge replacement project broken down by major deliverables. It utilizes a very simple coding structure that supports the levels of indenture. A separator, in this case a period, is added to the code at each level. Tracing the WBS from the bottom up, it is evident that the 1.1.2.1.1 *Piles* and 1.1.2.1.2 *Pile Caps* are components of 1.1.2.1 *Foundations* and that the *Foundations* are part of the 1.1.2 *Abutments*. The Abutments are part of 1.1 *Substructure*, which is one of three systems that comprises the project, 1 *Bridge Replacement*. This particular example is cost-loaded. The sum of the 1.1.2.1.1 *Piles* and 1.1.2.1.2 *Pile Caps*; $265,000 + $35,000 = $300,000 is the total cost of the 1.1.2.1 *Foundations*. The sum of the costs for the1.1.2.1 *Foundations,* 1.1.2.2 *Stem Wall,* and 1.1.2.3 *Wing Walls* is the total cost of the 1.1.2 *Abutments* or $785,000.

The outline depiction in Figure 8 is identical to the graphic WBS in Figure 7. The WBS and associated coding can be easily built using prevailing scheduling software such as the Primavera products, allowing for full reference to the WBS within a project's schedule. Most commercial project management software products including estimating and cost control packages include WBS functionality. Many practical benefits can be derived from producing a WBS. It is a mechanistic approach to organizing the answers to the *what, where,* and *why* questions. It is a very effective tool for capturing the physical scope of work, thereby defining the project. The end product provides the requisite input and/or structure into various other tools such as the budget, cost control system, cost models employed in value engineering, responsibility matrix, and risk management plan, among others. However, as is the case with so many processes, which produce useful business tools, it is not so much the destination as it is the journey. Production of a WBS requires that its creator(s) completely dissect the project. Learning is unavoidable. The WBS's producer(s) must at least learn the systems and constituent components of the project.

1. Bridge Replacement
    - 1.1. Substructure
        - 1.1.1. Piers
        - 1.1.2. Abutments
            - 1.1.2.1.Foundations
                - 1.1.2.1.1. Piles
                - 1.1.2.1.2. Pile Caps
            - 1.1.2.2.Stem Walls
            - 1.1.2.3.Wingwalls
    - 1.2. Superstructure
    - 1.3. Approaches

Figure 8 - WBS in Outline Form

Producing a WBS provides a framework that facilitates learning and organizing knowledge of the project. One cannot produce a reasonable WBS without understanding at least the physical features of the project. The depth of detailed understanding is a function of the level of indenture to which the project parts are described. The WBS can be decomposed or exploded literally down the nuts and bolts of the project. Obviously, there is a point of diminishing returns on expending the time required to obtain such detail. There is a level for most construction projects, usually the task activity level, below which information in neither required nor useful. There are of course limitations and even drawbacks to the WBS. These are discussed in critique section that follows later in this thesis.

3.5.2 Responsibility Matrix and Organizational Breakdown

The Responsibility Matrix (RM), sometimes referred to as the Responsibility Assignment Matrix (RAM) is a project management instrument built from the WBS used to ascribe and communicate responsibility for the all of the tasks associated with the project. The RM helps in answering the "*who*" questions. Task activities are often affected by multiple parties or entities and are assignable on various levels. For example, a given task requires someone to release or assign the activity, one or more separate parties to execute the activity, another party to support the flow through the activity, perhaps one or more to assess and/or approve the work, and yet another that requires notification of the activity's initiation or completion. The responsible parties may be internal or external members of the project team and at various levels of the organizational hierarchy.

A comprehensive RM assigns the responsibility for each activity to the accountable party or parties, regardless of affiliation. RMs often employs a coding system in describing the level of responsibility. A simple coding system may consist of single alphabetic characters to indicate the level of responsibility such as **A** for assign and/or coordinate, **E** or **X** for execute, **I** for inspect, **S** for support, **M** for monitor, **R** for review/approve, **F** for formal charge, and **N** for notify. The communication strength of these alpha designations can be enhanced by utilizing lower case or subscript characters to indicate hierarchical level or priority, i.e. **Ei, Eii, Eiii, Eiv**, etc.

Aligning all of the responsible parties in columns and placing the tasks in the matrix rows as shown in Figure 9 constructs a RM. It is also acceptable to arrange the tasks in the columns and responsible parties in the rows. The critical requirements of a RM is that it 1) includes each and every task required for project completion, at least to the level of indenture depicted in the schedule, 2) completely delineates all duties (assign, execute, monitor, etc.) for each activity, and 3) clearly communicates tasks and responsibilities without gaps, duplication, or ambiguity. Additionally, the RM must be distributed to and accepted by all responsible parties. The RM is a dynamic document and all changes to tasks and/or assignments must be posted and disseminated immediately to all parties. It is further critical that all affected parties acknowledge the changes and accept responsibility as defined in the revised document.

Responsibility Matrix Team: **DOT** Phase/Stage: **Preconstruction -- Prelim. Design**

	Responsibility														
Task	Chief Engineer	Bridge Engineer	Design Squad Leader	Geotechnical Engineer	Cad Operator 1	Cad Operator 2	Project Manager	Traffic Engineer	Environmental Studies	Maintenance Engineer	Safety Officer	ROW Section	Utility Section	Area Engineer (Constr.	Materials & Research
Appropriation Request	F/Ri	Rii	Rii				E			Rii				Rii	
Initial Public Workshop	N	Eii					Ei	Eii				Eii		Eii	
T.S.&L. Plans, Preliminary	Ri	Ei	Eii	Eiii	Eiii	Eiii	A/Rii	Eii	Rii	Rii	Rii	Rii	Rii	Rii	Rii
ROW Plans, Preliminary	Ri		Eii		Eiii		A/Rii					Ei		N	
Utility Plans, Preliminary	Ri		Eii		Eiii		A/Rii						Ei	N	
Geotechnical Report	Ri		Eii	Ei		Eiii	A							N	Rii
Environmental Impact Statement	Ri	Rii					A		E			Rii		N	
404 Permit Application	F/Ri						A		E					N	
MOT Plans, Preliminary	Ri	Rii	Eii			Eiii	A/Rii	Ei			Rii			Rii	
Striping and Signage Plans, Prelim.	Ri	Rii	Eii			Eiii	A/Rii	Ei		Rii	Rii			N	Rii

Figure 9 - Responsibility Matrix

As in development of the WBS, preparation of the RM yields corollary benefits beyond the written instrument. It stimulates learning and dissemination of knowledge of the project.

Once again, it is not merely the destination, but the journey. Preparation of a RM is effective in risk reduction through early identification of the required tasks and assignment of each party that must perform specific action(s) in order to successfully complete those tasks. RMs can be prepared using various commercial software, but is more commonly generated using an electronic spreadsheet package such as Excel. The Excel output is valuable as a standalone display and also supports schedule development. The RM assignments serve as input in building the resource dictionary within the Primavera schedule database. While the RM can be a valuable tool to aid in effectively managing projects, there are certainly limitations and drawbacks that will be discussed in the critique section. One fundamental limitation is that many organizations within the highway industry lack maturity in project management to the point of not using (or lack familiarity with) the RM.

An Organization Breakdown Structure (OBS) is tool used to depict responsibilities on an organizational level. It displays how the team is organized to discharge work responsibilities (Gray and Larson 2008). The OBS is useful in identifying the organizational unit responsible for various work packages. It provides a framework for connecting organizational units to cost accounts for budgets and schedules. As such, it aids in tracking, assessing, and summarizing in terms of time, cost, and technical performance. The OBS views responsibility at a higher level than the RM. Whereas the RM assigns crews and individuals to tasks, the OBS identifies the organization units to which crews and individuals belong. Traditional organization structures can form the basic configuration of the OBS. Graphically linking the OBS with the WBS integrates work and responsibility at the organizational level as shown in Figure 10.

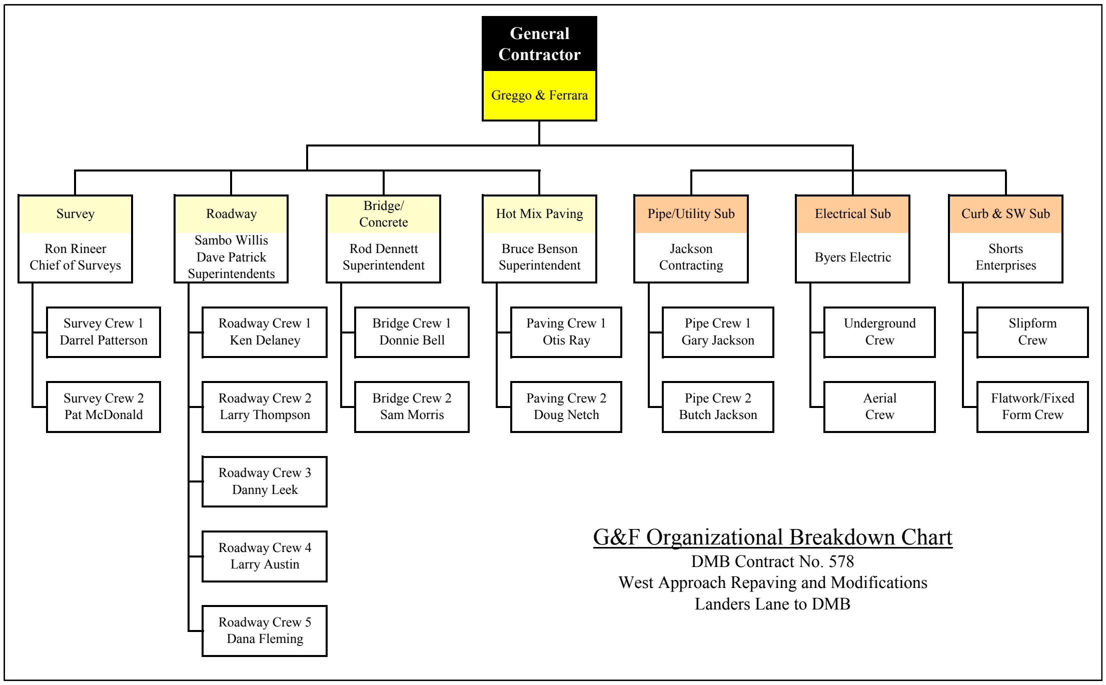

Figure 10 - Organizational Breakdown Chart

3.6 Scheduling

Once the planning products are produced, the team can begin the scheduling process. The scheduling process roughly answers the question, *when*? The project schedule is the key component of any time management program. There are various types of schedules and methods of modeling time. The most prevalent practice in the highway construction industry is the Critical Path Method or CPM. CPM is a form of network scheduling in which all of the tasks required to complete the project are sequentially arranged in paths or chains of activities. Schedulers attempt to model the project through the logic displayed across the network. Bar charts are regularly used to portray and communicate the project schedule, often presenting the network output. Another scheduling technique available to, but largely unused by the highway industry is the Linear Scheduling Method (LSM), more currently referred to as Location-based Scheduling. The information that follows includes a discussion of the historical development of construction scheduling, the mechanics of network and location-based scheduling, and practical application of the various scheduling techniques.

3.6.1 Historical Development

Critical Path Scheduling (CPS) as early users referred to it, can be traced to the 1950's during which time two independent efforts were launched to leverage computer technology to improve the timeliness of project delivery (O'Brien and Plotnick 2010, Riggs 1976, Fondahl 1962). The United States Navy in conjunction with prime contractor Lockheed Aircraft Corporation and consultant Booz, Allen, and Hamilton, developed a CPS technique initially launched as *Program Evaluation Research Task* then coined *Program Evaluation and Review Technique* and later called *Project Evaluation and Review Technique* or PERT[20] as a tool for managing projects within the Polaris ballistic missile program. PERT was first applied to research and development projects within the Polaris program, yielding favorable results (Moder and Phillips 1970, Fondahl 1962).

While the Navy team was developing PERT, the DuPont Company and Remington

[20] PERT is sometimes defined as "Project" Evaluation and Review Technique or "Performance" Evaluation and Review Technique. In this sense, both are synonymous with the probabilistic network scheduling method originally known as Program Evaluation and Review Technique. Primavera Systems, Inc. used PERT as the name of their graphical network displays in various versions of Primavera Project Planner (P3) scheduling software in the late 1990s.

from Univac providing the technical expertise and was originally designated *Project Planning and Scheduling System* (Fondahl 1962). The project was actually launched to find practical applications for the UNIVAC1 computer at DuPont (first computer installed in a commercial business) (Weaver 2008). The outcome was an early version of CPM, which was developed to better manage complex plant engineering and construction work. Neither of the two teams, the Navy nor DuPont – Sperry Rand was aware of the other team's developments (Newitt 2009, Moder and Phillips 1970). DuPont applied the new scheduling technique to projects at their Louisville, KY plant. The first three trial projects met great success with the third very sensitive project realizing significant time saving over previous performance on similar overhaul projects (O'Brien and Plotnick 2010). The individuals largely responsible for the DuPont – Sperry Rand work (Mauchly, Kelley, Walker and others) became the firm of Mauchly Associates. The firm presented several workshops across North America intended to acquaint constructors with the power and application of CPM and were largely responsible for the early dissemination and adoption of the new scheduling technique (Fondahl 1962)

Although CPM and PERT were developed independently, network logic diagramming[21] is the underpinning theory for both techniques. One original difference between the two techniques is that PERT is probabilistic in determining activity durations, while CPM uses deterministic or fixed single durations for each activity. PERT utilizes a duration range varying from pessimistic to optimistic. Duration computation is based on a weighted average of the range with a factor of our (4) applied to the most likely time requirement. The algorithm determines an expected time "t"

[21] Also referred to as *network based management systems* (Weaver 2008)

rather than a specific fixed duration. The equation for "t" is shown in Figure 11 where "a" is the optimistic time estimate, "m" is the most likely, and "b" is the pessimistic projection. Since time estimation in PERT is probabilistic, the variance (σ^2) and standard deviation (σ) are parameters necessary for computing and interpreting the schedule and are also shown in Figure 8.

$$t = \frac{a + 4m + b}{6} \qquad \sigma^2 = \left[\frac{b - a}{6}\right]^2 \qquad \sigma = \frac{b - a}{6}$$

Figure 11 - PERT Formulas

2.3

In 1958, the U.S. Navy's Bureau of Yards & Docks engaged Dr. John Fondahl, a Construction Engineering and Management Professor at Stanford University to search for ways of improving productivity. One of the major outcomes was Dr. Fondahl's report: *A Non-computer Approach to Critical Path Scheduling* in 1961, second edition in 1962. His proposed methodology for modeling project networks placed activities on nodes in what he referred to as the *circle and connecting line notation* or *circle notation* (Fondahl 1962). The original CPM approach placed the activities on arrows within the network, connected at junctions referred to as nodes. These nodes were presented as circles or other closed geometric figures (square, rectangle, or oval) that were designated as events or points in time with no duration. The arrows presented the activities and indicated the flow of work through the chain. The arrangement modeled the interdependent relationships between activities. This format is referred to as activity-on-arrow (AOA) diagramming or activity diagramming method (ADM) as shown in Figure 12. In circle notation or the activity-on-node (AON) approach, the activities are described on the nodes as shown in Figure 12 with the arrows only indicating dependencies or relationships. Note that the networks shown in Figures 12 and 13 are identical in both content and logic. Today, CPM is presented on either AOA or AON networks. However, AON is the prevailing graphic methodology since it is the format upon which the precedence diagramming method (PDM) is built. The most prevalent scheduling packages used in construction, including the Primavera windows platform products and Microsoft Project are based on the PDM network.

Fondahl continued to refine the methodology at Stanford. Simultaneously, some of his former students, working for H.B. Zachry Company in Texas, teamed with IBM to

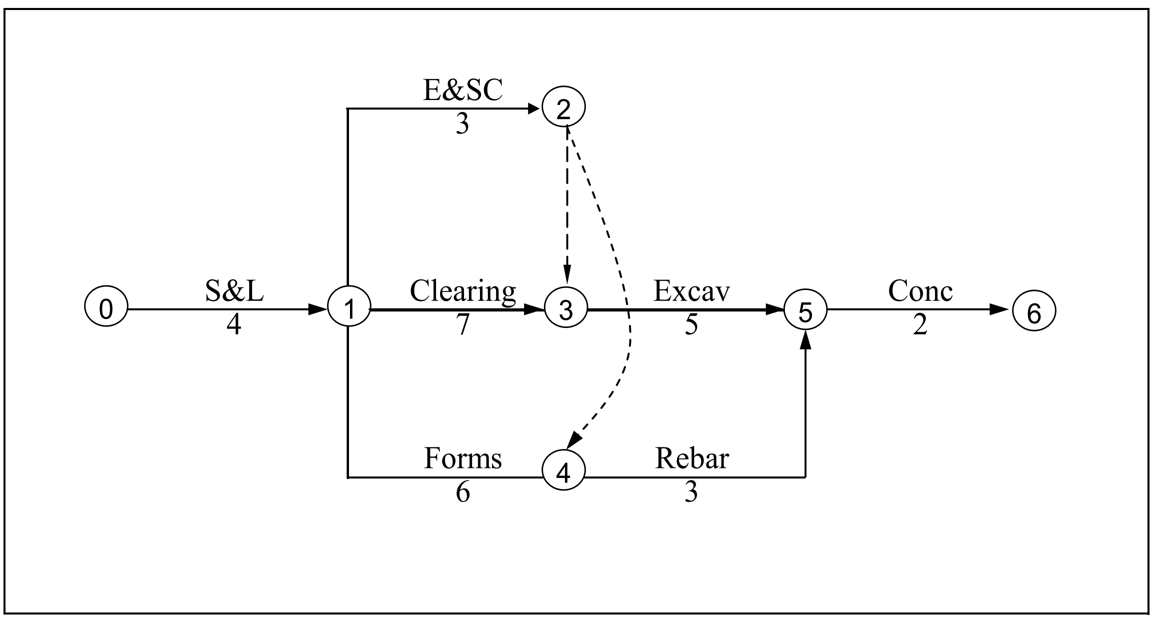

Figure 12 – Activity-on-Arrow (AOA) Diagram or Arrow Diagraming Method (ADM)

further expand network scheduling techniques, ultimately producing PDM[22] (O'Brien and Plotnick 2010, Weaver 2008). The expanded version of PDM allowed logical relationships other than the finish-to-start (FS), i.e.: start-to-start (SS) and finish-to-finish (FF) and included the use of lag time between activities. In 1964, the culminating deliverable was an IBM software program titled *Project Control System* (PCS) that included use of lags and alternate logical relationships (Weaver 2008). Previous CPM network requirements mandated that all predecessor activities be 100% complete prior to starting the successor activity. The departure from this rule allowed fewer activities to more accurately portray the project work plan.

Prior to the development of CPM, construction practitioners utilized an industrial engineering tool for scheduling. That tool, the bar chart, was developed[23] by Henry L. Gantt in the 1910's to allow foreman and management personnel to determine whether work was on-schedule, behind schedule, or ahead of schedule. Gantt's efforts, along with those of his mentor, Frederick Taylor, are credited with birthing and propagating scientific management principles in industry (O'Brien and Plotnick 2010). Gantt's portrayal of the work plan places activities vertically in approximate chronological order from the top of the chart. The timescale is placed horizontally along the X-axis. The advantages of the Gantt chart[24] include the ease of producing and updating the chart along with the ease of reading and interpretation.

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[22] The Stanford team adopted the name PDM from IBM though the network configuration was based on Fondahl's circle-and-connecting-line technique (Weaver 2008)

[23] Others prior to Gantt may have used a similar type of bar chart, but he is credited with its development as a production control tool (Weaver 2008)

[24] The name "Gantt chart" is synonymous with the term "bar chart"

The schedule information presented on the Gantt chart is relatively easy to comprehend, making it an excellent tool for communicating the work plan to the various stakeholders. The major disadvantage of the bar chart is that it does not show interrelationships or logical dependencies. While some dependencies may be inferred, the bar chart does not display the all-important logical flow of the work plan. The bar chart does not provide sufficient detail to effectively evaluate schedule impacts. It therefore, does not provide adequate documentation for assessment of claims for delay or disruption. More importantly, it is ineffective as a stand-alone time management tool for

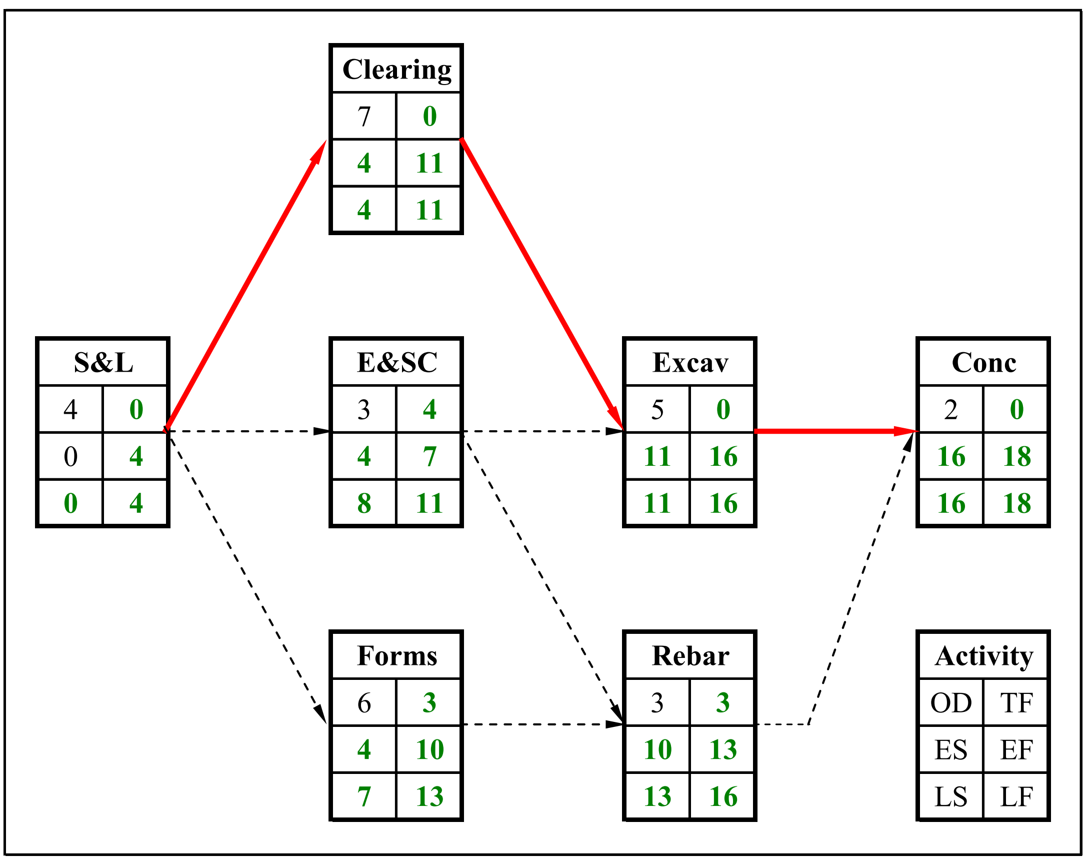

Figure 13 - Activity-on-Node (AON) Diagram

the purposes of planning and executing construction. Modern scheduling software such as Primavera presents a bar chart view of the CPM network, which provides the benefits of an easy to read display that is determined by logical relationships.

3.6.2 CPM Network Basics

The schedule network is essentially a flow chart that graphically depicts the sequences, interdependencies, start and finish times, and other data related to all of the activities required to complete a project. It yields an estimate of the project duration, provides the basis for scheduling labor and equipment, and facilitates budgeting through cash flow projections. CPM networks provide managers with an indication of critical activities that should not be delayed in order to meet the project's required completion date. It is an invaluable tool (not without limitations) to aid in the planning and guiding the execution of project work. CPM network development requires considerable time, effort, and experience in order to develop a realistic diagram. It must reflect and drive the actual work plan to be of any value. It also must be kept current to be of any real value. Again, the best schedules are developed collaboratively upon the consensus of the project team.

CPM networks display the project activities and flow graphically through the use of logic ties. Time is typically not reflected graphically[25]. The network presents activities as they relate to each other. A network is comprised of several paths or chains of interconnected, interdependent activities. An individual activity follows a prerequisite predecessor activity(s) and is in turn followed by a dependent successor activity(s). Activities and the chains or paths they form may be concurrent or parallel in addition to

[25] Time and relationships can be reflected graphically through time-scaled logic diagrams and to some extent using fenced bar charts.

the continuous predecessor-successor arrangement. Concurrent path activities can occur independently and, if desired, not at the same instance as long as they occur within their computed time boundaries. An activity is defined as a "burst activity" when a single path branches off into two or more paths from that point. When multiple paths join into one common path, the activity at this junction is referred to as a merge or converging activity[26]. Networks typically flow from left to right from a single initial activity to a single terminal activity. In the original CPM formats, an activity cannot begin until all of its predecessor activities are complete. This rule has been modified in PDM, but holds true in ADM and PERT. Arrows indicate precedence and flow, and can cross over each other. The network must contain a unique identifier for each activity, regardless of the type of network. Continuity must be maintained through the network such that there are no "dangling" activities. This requires that each activity have at least one predecessor and at least one successor; the exceptions of course are the initial and terminal activities. Looping is fundamentally backwards logic and is never allowed in network scheduling[27]. The Critical Path is the longest path through the activity network that allows for the completion of all project-related activities. It is the shortest expected time in which the entire project can be completed. Delays on the critical path will delay completion of the entire project.

The duration of the project as well as all of the boundary dates for the individual activities can calculated by one of two algorithms commonly referred to as the Forward Pass and Backward Pass. The boundary dates are the early start (ES), early finish (EF),

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[26] This junction point is also referred to as a "sink" point (Kerzner 2009)
[27] A probabilistic technique similar to PERT known as the Graphical Evaluation and Review Technique or GERT allows looping and other logic options not allowed or supported by ADM, PDM, or PERT (Kerzner 2009)

late start (LS), and late finish (LF). The ES and EF are earliest dates that an activity can begin and finish based on the logic that precedes the activity in question. The LS and LF are the latest dates by which the activity must start and finish without delaying completion of the project. Total float is the difference between the early and late dates, i.e.: TF = LS – ES or LF – EF. Total float, also referred to as "slack" is viewed as a commodity within the schedule and is a quantity that certainly influences management decisions through the course of the project. The forward pass determines the early dates (ES and EF) and the overall project length or duration. The late dates (LS and LF) are computed through the backwards pass, after which the TF can be calculated.

Mechanically, the forward and backward passes involve simple arithmetic; addition and subtraction slightly complicated by decision rules necessary to treat converging paths. The forward pass is performed from the initial activity through the entire network from left to right ending at the terminal activity. The start date for the project is the ES of initial activity. When the schedule is calculated simply using working days, an ES = 0 can be used. This is referred to as End-of-Day Convention since the start is interpreted as occurring at the end of Day 0 (effectively the beginning of Day 1). Using End-of-Day Convention results in an activity being completed at the end of the day. The Beginning-of-Day Convention would mean the ES of the initial activity equals 1 and translates into the finish date being at the beginning of the day[28]. Various scheduling software uses a modified version of Beginning-of-Day Convention to compute boundary dates, which will be explained here shortly. In executing the forward pass, the activity's duration is added to the ES to obtain the EF (ES + Duration = EF). The EFi is carried to the next

[28] Beginning of the day after the date computed using End-of-Day Convention.

activity where it becomes the successor's ESj. That is unless the next succeeding activity is a merge activity, in which case the largest or latest EF of all preceding activities is selected. This is repeated through the entire network to the terminal activity. The backward pass is then executed from the terminal activity back through the network proceeding right to left until returning to the initial activity.

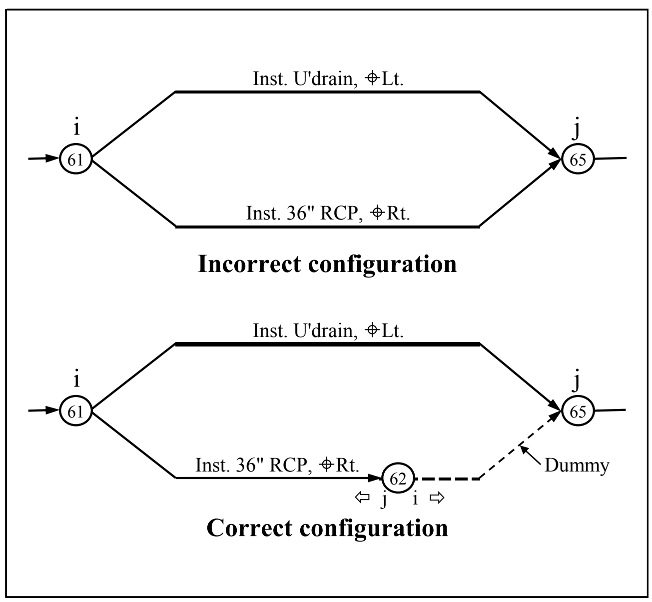
The backward pass begins by assigning the EF of the terminal activity as its LF. The activity's duration is subtracted from the LF to determine the LS (LF - Duration = LS). The LS is then carried to the upstream activities where it becomes the predecessor's LF. That is unless the predecessor activity is a burst activity, in which case the smallest or earliest LF of all successor activities is selected. This process is repeated through the entire network until reaching the initial activity. With few exceptions, the initial activity's late dates should equal the early dates. Once the backward pass is complete and all of the LS and LF dates calculated the TF can be obtained by subtracting the early dates from the late dates (LF – EF or LS – ES). For an original schedule, with few exceptions, the critical path follows the chain of activities in which the TF = 0[29]. Upon updating the schedule as the work progresses, the critical path flows along the chain with the least float

Free Float is another type of float that can be calculated after completing the backwards pass. Free float is the amount of time an activity can be delayed without delaying the early start of connected successor activities. In other words, Free Float is the amount of time an activity can be delayed without reducing float in succeeding activities (Newitt 2009). Mathematically, Free Float (FrF) = earliest or minimum ES_{i+1} –

[29] Original schedule networks that are artificially constrained may have portions of the critical path in which the TF ≠ 0.

EF_i, meaning FrF is equal to the earliest of the ES dates for the successor activities less the EF of the activity in question[30]. It is important to recognize that FrF ≤ TF. FrF = 0 determines existence of driving relationships meaning that the predecessor sets the pace for the successor(s). The concept of FrF provides deeper insight and understanding of network relationships. Interfering Float (IntF) is that which will delay the ES of a successor activity(s) without delaying the entire project (Mubarak 2010). IntF is also referred to as string or path float, but more commonly as shared float (Newitt 2009). FrF and IntF are components of TF where TF = FrF + IntF or IntF = TF – FF. Independent Float (IndF) on the other hand is TF that is neither shared with nor affected by any other activity. IndF can only exist if the activity has FrF (Hinze 2008). It is vitally important that managers understand the various types of float and the ramifications of each.

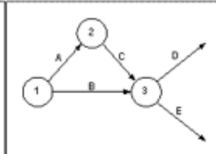
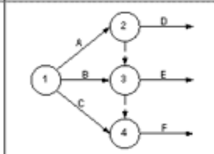
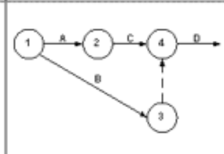
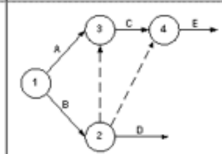
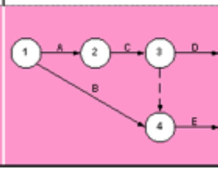
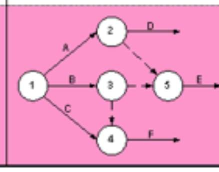
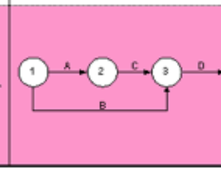
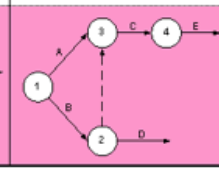
Figure 14 - i-j Node Usage



As previously discussed, ADM places the activity on the arrow and provides interconnection between activities at nodes which are conceived as events or points in time. ADM uses ij notation, which was borrowed from linear programming (Weaver 2008). An activity is uniquely identified by it "i" node at the tail or beginning of

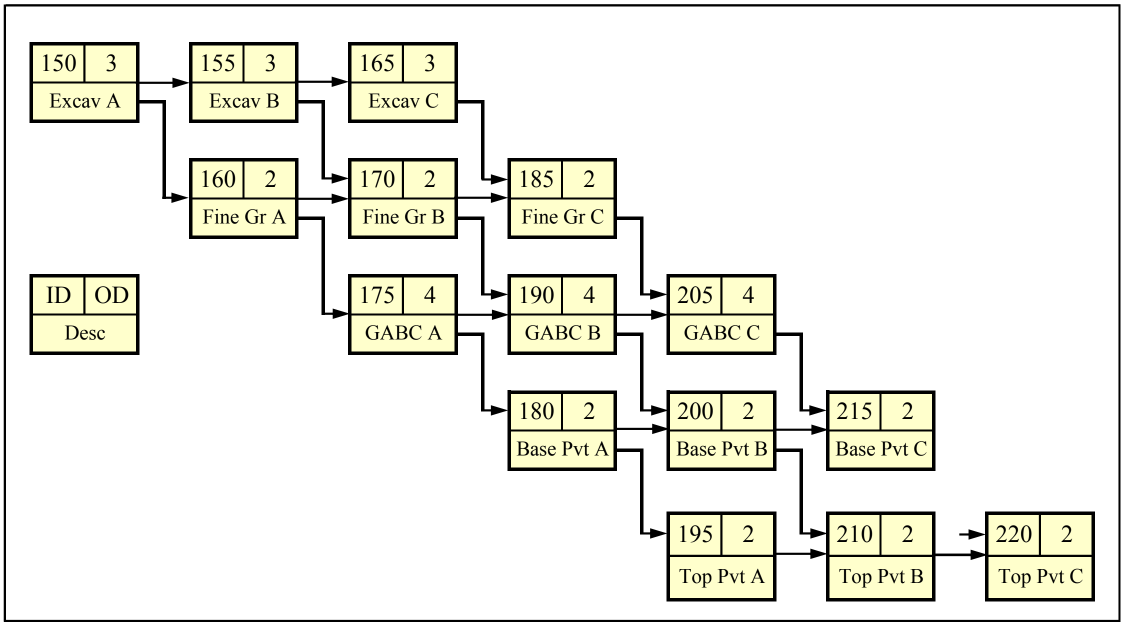
[30] The author uses the abbreviation FrF to indicate Free Float and FF to indicate a Finish-to-Finish relationship. Most texts use FF to represent both Free Float and Finish-to-Finish relationship

Table 2 – Correct and Incorrect Use of Dummies

Case	Spillover	Cascade	Unnecessary	Redundant
Logic ties	A⇨C B⇨E C⇨D,E	A⇨D,E B⇨E,F C⇨F	A⇨C B⇨D C⇨D	A⇨C B⇨C,D,E C⇨E
Incorrect network segment				
Error	B is not a prerequisite of **D**	A is not a prerequisite of **F**	Artificial dummy 3,4 is unnecessary	B is a redundant restriction on **E**
Correct network segment				

the arrow and its "j" node at the head or end of the arrow. While activities may share an "i" node or a "j" node, two or more activities are prohibited from simultaneously sharing the same "i" and "j" node. This is graphically presented in Figure 14. The requirement of unique i-j pairs is one necessity for the inclusion of "dummy" activities. *Artificial dummies* are activities used to facilitate node numbering to avoid duplicate i-j pairs; an essential requirement of the early computer programs. *Logic dummies* or restraints are required to correctly depict dependencies between activities (Riggs 1976). Table 2 shows the correct and incorrect use of network dummies. While ADM is becoming archaic at this point in time, the author believes as other experts do, that comprehension of this technique leads to deeper understanding and appreciation of network scheduling. One practical drawback of ADM is the limitation of using only finish-to-start relationships.

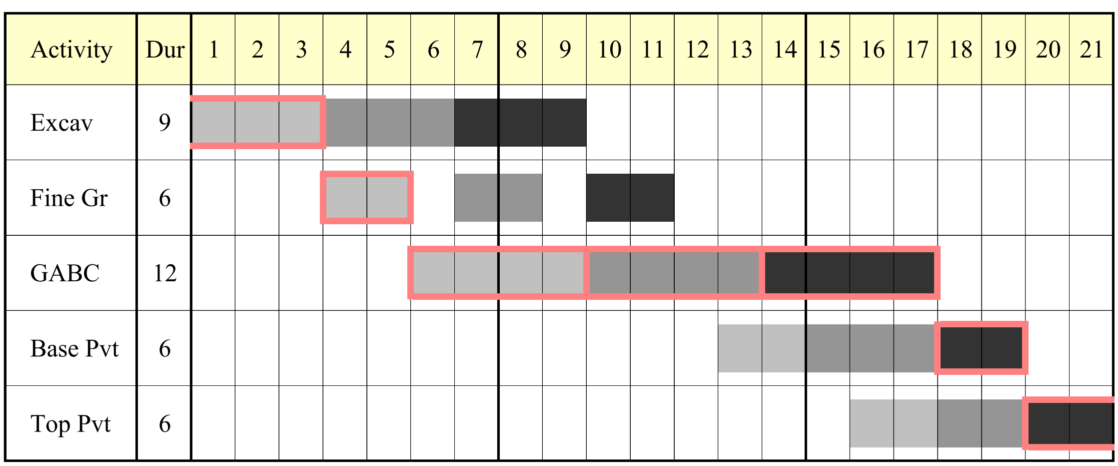
Figure 15– Laddering Example



The most common logical relationship is the finish-to-start (FS), in which the successor activity is dependent upon the entire completion of the predecessor activity(s) before it can begin. The succeeding activity cannot start until completion of preceding activity. Many contract specifications as well as managers insist on only using FS relationships. However, such an arrangement may or may not practically represent reality. One approach to overcome this problem is laddering (Gray and Larson 2008). It entails breaking an activity(s) into segments and reconnecting in the configuration that somewhat resembles a ladder or more precisely, stair steps as shown in the example in Figure 15. The laddering example shown allows work to progress concurrently on a stretch of new roadway without physical interference or crew conflict. Figure 16 is a bar chart depicting the timeline of the laddered network. Note in the example that if the work were planned and executed in a purely linear fashion, the total duration would be considerably more than the laddering approach. In other words, if all of the excavation must be completed prior to starting fine grading, and all of the fine grading completed before starting the graded aggregate base course (GABC), and so on, the overall duration would be 39 working days (WDs). Laddering provides the logic for the same amount of work to be completed in 21 WDs; as savings of 18 WDs. Alternate methods to laddering for accomplishing the same result are available within the PDM framework.

2.4

Figure 16 – Bar Chart of Laddering Example



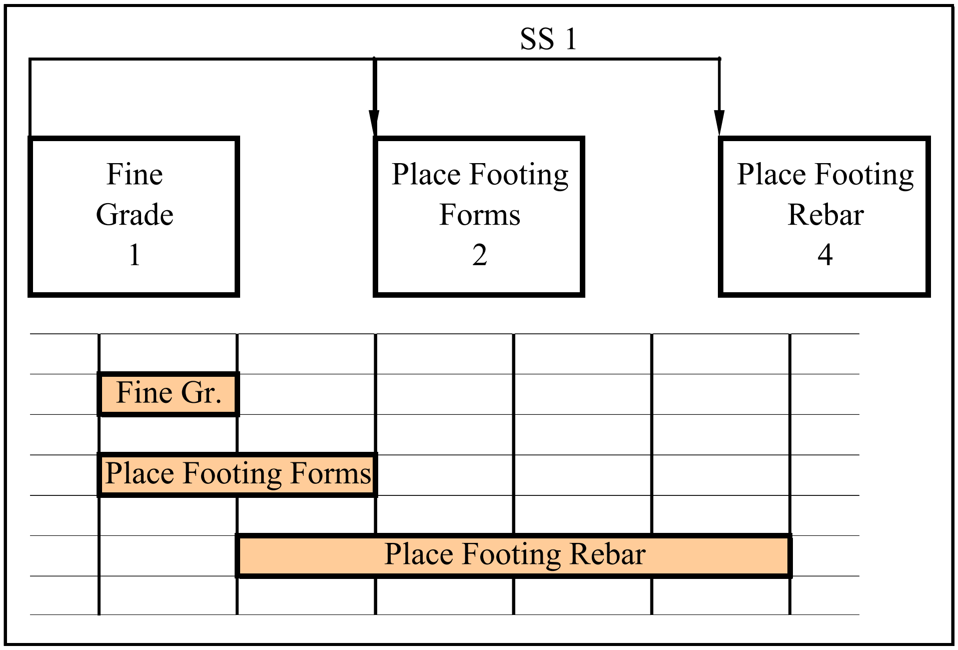


Figure 17 - Finish-to-Start (FS) with Lag

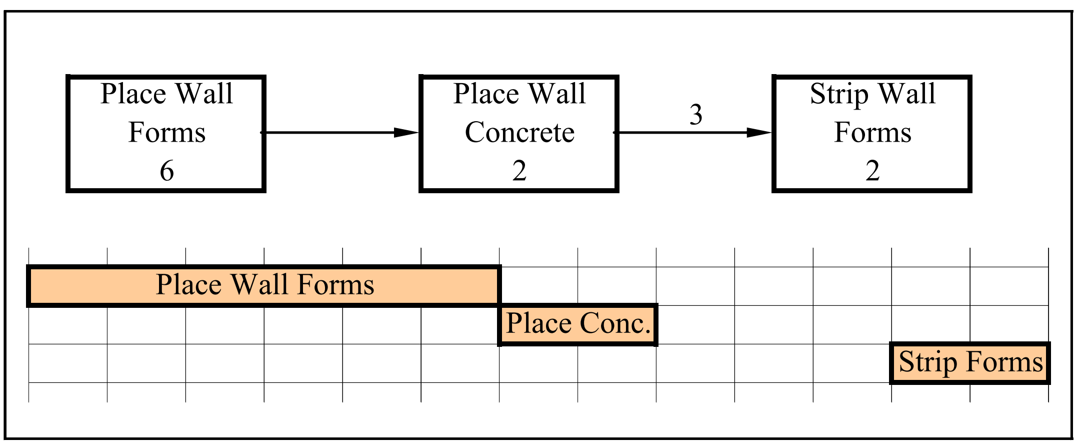


Figure 18 – Start-to-Start (SS) Relationship

PDM allows the use of lag time between activities, which essentially delays the start or finish of the immediate downstream activity. A finish-to-start relationship with lag (L) is illustrated in Figure 17 In this case, the FS relationship with 3-days lag between placing concrete and stripping form represents the time required for curing. Of course, this could be accomplished by inserting an activity for curing. The use of lags enables schedulers to more closely present the proposed work plan while reducing the number of activities to do so, as opposed to laddering which expands the number of activities. Lags are generally positive integers, but they can also include negative values. Negative lags are

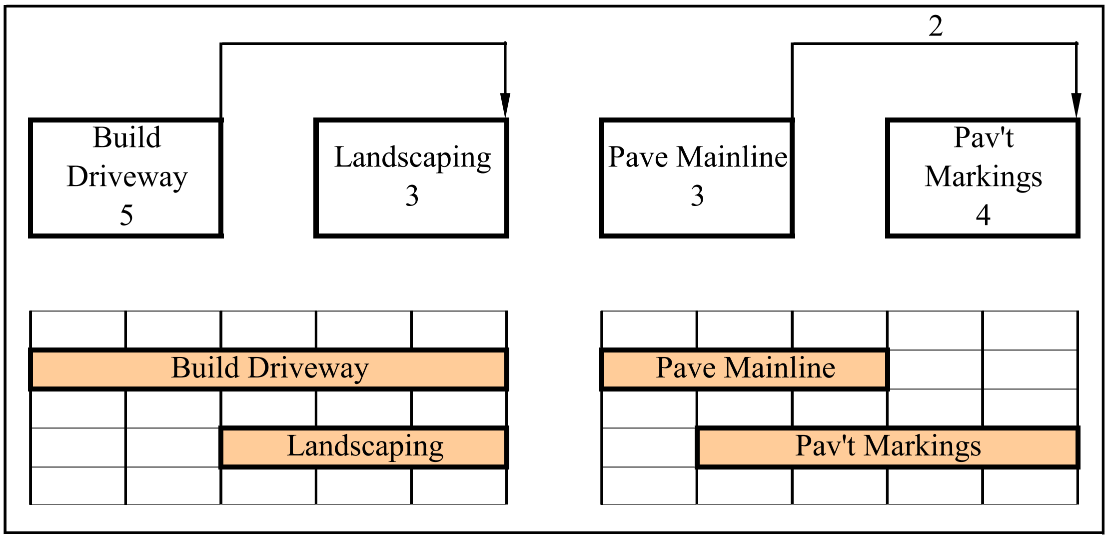


Figure 19 – Finish-to-Finish (FF) Relationship

usually referred to as *leads* (Kerzner 2009). The use of lags is a mixed bag, so to speak. While lags can simplify the schedule by reducing activities, they can also make it more complicated and hinder communication by masking requirements that consume time, e.g.: curing. PDM also allows the use of alternate relationship with or without lags; namely start-to-start (SS) and finish-to-finish (FF)[31]. In a SS relationship, the start of a successor activity is dependent upon the start of the predecessor activity and may include lag time. Likewise, a FF relationship relates the finish of the successor activity to the finish of a predecessor activity. Examples of alternate SS and FF relationships are shown

[31] Some literature and Primavera products support start-to-finish relationships. Such relationships are essentially backwards logic prohibited in all forms of CPM. The author does not advocate use of start-to-finish relationships

in Figure 18 and 19.

PDM calculations performed in software programs typically use a combination of beginning-of-day and end-of-day conventions for an activity's ES/LS and EF/LF respectively. Doing so results in boundary dates that are more meaningful and realistic. Work is reflected as starting at the beginning of the day and finishing at the end of the day. The EFi is computed as ESi + RDi – 1, where RDi is the remaining duration (RD) of Activity i. The calculation uses the activity's remaining duration since the parameter remains relevant throughout the entire life cycle of the schedule. The life cycle of a CPM schedule consists of the original baseline schedule, each subsequent update, mock or "what-if" schedules, and the final as-built version. The RD is the relevant duration parameter since the RD = OD for an original schedule since no time has been consumed at that point. However, after an activity that has started and effectively consumed time, the RD ≠ OD. Reflecting progress or "statusing" an activity requires that the RD ≤ OD - 1[32]. The ES of a successor activity with a FS relationship is computed as ESj = EFi + Lij + 1, where adding "1" essentially represents the overnight period. The forward pass rules for convergence are applied after considering lag, thereby rendering the latest possible ESj. The backward pass calculations are LS = LF – RD + 1 and LFi = LSj – Lij – 1.

Forward and backward pass calculations with SS and FF relationships are computed in a similar fashion as FS and are bound by the same selection rules at convergence or sink points. One exception is that there is no overnight period to

[32] "Statusing" is an action or process term used in scheduling practice meaning "to determine status". Statusing consists of inputting an activity's actual start (AS) and actual finish (AF) which supersedes the early and late boundary dates in the forward and backward pass calculations. Scheduling practice dictates that the RD must be reduced to a maximum value of OD – 1 in order to be valid.

consider. The forward pass calculations in SS relationship include ESj = ESi + Lij and EFj = ESj + RDj – 1. FF relationships are not as straightforward in that the EFj is needed to compute the ESj, where ESj = EFi + Lij – RDj + 1. Conversely, the backward pass for a FF relationship is rather straightforward where the SS requires similar manipulation as the FF does on the forward pass. For a FF, LFi = LFj – Lij and the LSi = LFi – RDi + 1. In a SS, LFi = LSj – Lij + RDi – 1. Obviously, the LSi = LSj – Lij.

As stated, networks consist of paths or chains which are essentially logical assemblies of activities required to complete a project. An activity is a detailed component of work. An activity can encompass various amounts of work depending upon the nature and purpose of the schedule. A preliminary schedule prepared for a feasibility study may contain high-level (WBS) activities that represent phases or large chunks of work in very low detail. Such a schedule contains activities with long durations that lack responsibility and resource assignments. On the other side of the spectrum, schedules that are produced to plan, execute, and control work are far more detailed and contain many smaller activities. What is the proper size or magnitude of work for each activity? That is going to be a function of culture and the need for detail. This will vary from organization to organization and from project to project. Regardless of magnitude, the vast majority of activities can be categorized as task activities.

While all activities have calculable starts and finishes, task activities exhibit other clear characteristics. First of all, a task activity is intended to accomplish something tangible. It is therefore measurable and quantifiable. Its completion can be verified, as can its partial completion, although that measurement can be somewhat nebulous or subjective. Secondly, a task activity consumes time. A hard and fast rule is that a task activity must consume at least one planning unit of time in order to execute and complete the intended work. Planning units (of time) can be stated in terms of years, months, weeks, days, minutes, and even seconds. High-level schedules can use the larger planning units of months or even years, but most construction schedules consist of tasks with durations measured and stated in days. The author has on occasion utilized hour-based schedules for emergency repair projects and for around-the-clock traffic pattern realignments, an example of which is shown Figure 20. Schedule network rules mandate that regardless of which planning unit is utilized; mixing of units within a given network is forbidden. Planning units must be kept consistent through the entire network. A schedule is not valid say, if it has some activity durations stated in days and others stated in weeks. All durations must be measured either in weeks or days, not a mix of the two. Whole units are required. Partial units such as 0.5 days may not be used to describe an activity's OD nor its RD.

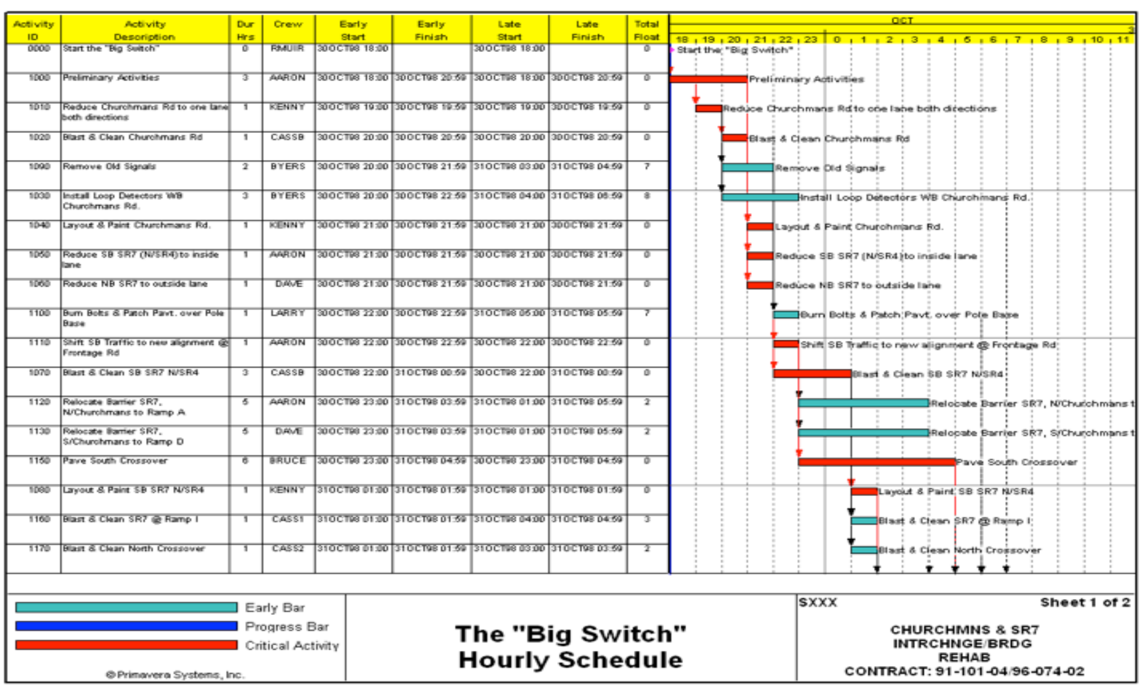


Figure 20 – Hourly Schedule Example

A task activity consumes resources through its execution. Scheduling software programs enable task activities to be resource-loaded; reflecting the resources requirements for each activity. Resources and their constraints are loaded into the resource dictionary for the project and applied to the individual tasks. The required resources can be in the form of labor or manpower, equipment, materials, financial resources, and/or information. Some would argue that space should also be considered as a resource. General contractors, consulting engineering firms and others that self-

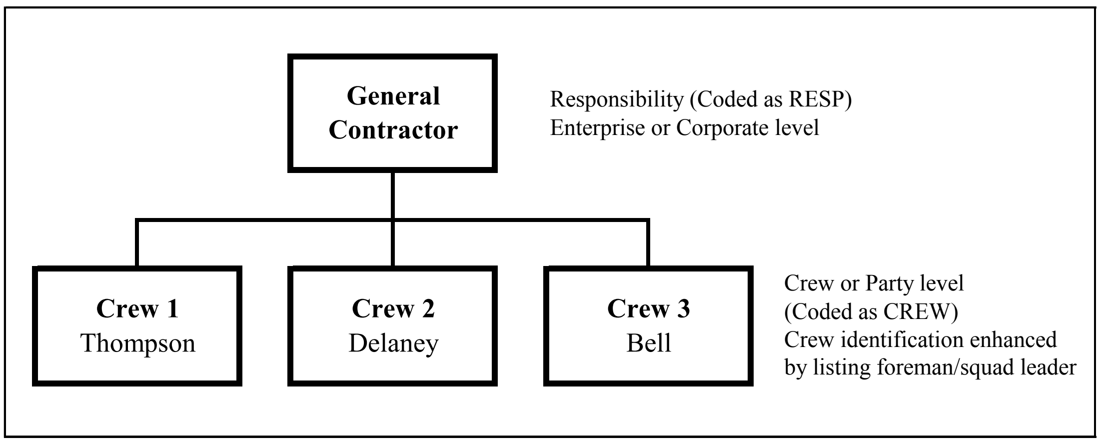


Figure 21 – Project Organization Hierarchy

perform a portion of the project work may categorize subcontractors or subconsultants as distinct resources to differentiate from work performed by in-house labor. The rationale is that the management effort and control of external labor forces, i.e.: subcontractors and subconsultants vs. in-house labor is significantly different. Task activities can require multiple resources that must be concurrently available in order for the work to be executed. Scheduling software allows task activities to be configured in a manner that reflects that reality. Moreover, scheduling software can allow the schedule to be driven by resource availability, and not purely by logic; a technique referred to as Resource

Leveling. This approach can be effective when scheduling activities within a given project, and particularly useful when scheduling multiple projects across an enterprise with a finite pool of resources. Task activities are assignable, that is, an entity(s) can be assigned some responsibility for the activity. As noted in the section under the Responsibility Matrix (RM), task activities are assignable on many levels and various duties such as execution, supervision, inspection, etc. Software packages facilitate this assignment through activity coding. Assignment should encompass the components of the OBS and RM. Multiple duties and levels of responsibility can be assigned via activity coding. The Activity Code dictionary is loaded with the various parties' identifying information and then assigned appropriately to each activity. Typically, construction work can be coded and organized by organization then by crew(s) or party(s) as depicted in the graphical hierarchy in Figure 21. An activity whose execution can be assigned to multiple organizations is probably too large in scope or magnitude. Actually, a good approach to establishing the size of task activities is to limit the scope to work that can be accomplished by a single crew or party.

Milestones are commonly referred to as activities used in network scheduling to denote significant points in the project[33]. Milestones are more accurately defined as events. An event is a point in time delineating the start or completion of an activity or chain of activities (Mubarak 2010). Milestones are often used to indicate transition points, such as the conclusion of major portions of the work. They are also used to indicate contractually significant points or dates. The basis and timing of payments can be attached to the achievement of various completion milestones. Start milestones are

[33] Various software producers and contract specifications refer to milestones as a type of activity.

often triggers initiating a chain of actions or reactions. Such milestones are a schedule's control points. Milestones linked to inspections are an example. Other milestones are more symbolic. Unlike a task activity, an event does not consume time or resources. Milestones do not have duration so are therefore statused as "not started" or "complete", never as "in progress". The initial and terminal activities in a network should be Start and Finish Milestones respectively. Moreover, milestones partition chains into stages or phases and serve as practical bookends for major segments of work. Using milestones in this way effectively compartmentalizes the project, rendering it easier to understand and manage. Utilizing milestones at critical intervals helps to set and maintain takt time or pace for the project. Timely achievement of milestones provides the psychological benefit of goal realization, encouraging the project team forward.

A Hammock Activity is a summary activity, which spans over a segment of a project network. Hammock activities are used to aggregate portions of the project to summarize specific sections without sacrificing the detail found in the parallel component activities. A network section showing a Hammock Activity and its parallel chain is displayed in Figure 22. As shown, the Hammock Activity derives its boundary dates from the parallel chain. More specifically, the Start dates (ES and LS) are derived from the first activity and the finish dates (EF and LF) from last activity of the parallel chain. The duration (OD or RD) of the Hammock Activity is total duration from the activities in the parallel chain. In this example, Activity 10055 Close Ramp B, Maintain Detour, B is the hammock activity that runs simultaneously with the substructure rehabilitation work along Ramp B. This includes the west abutments for the 8^{th}, 9^{th}, and 10^{th} Street Bridges over I-95 in Wilmington, DE. The closure and required detour start dates equal the start dates for Activity 10063, which is the first of nine activities in the parallel chain. The late dates equal those of Activity 08070 Open Ramp B, which is the last activity in the chain. Software programs that incorporate Hammock Activities automatically recalculate those activities when any of the individual parallel activities are updated. As Newitt explains, a Hammock Activity can also be one that is necessary to support a parallel chain of activities such as maintaining a haul road during various earthwork operations, not necessarily summarizing those activities (Newitt 2009). In this way, the Hammock Activity is valuable in that it accounts for necessary work and the associated resources.

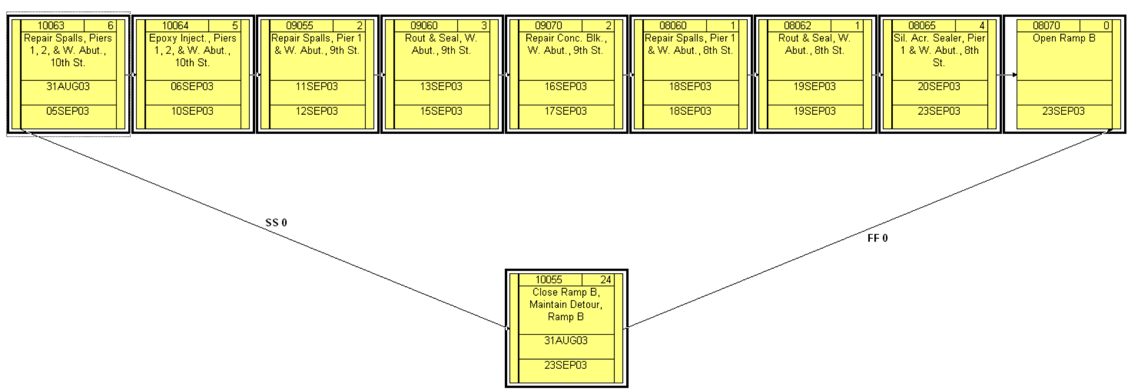


Figure 22 – Hammock Activity with Parallel Chain

3.6.3 Preparing the Network

Preparation of the network schedule begins by drafting a rough logic diagram. Most schedulers choose to develop the logic diagram by hand rather than computer (Newitt 2009). It is easier and more efficient to produce the logic diagram manually in graphic format and somewhat cumbersome to produce directly in a computer. Graphical logic can be difficult to work with from a screen, especially in a process of concurrent collaboration. The most effective approach is to create the rough diagram in team environment and that is best performed manually around a conference table. A few companies have begun using whiteboard technology that captures network images, but the author has not found any evidence to indicate wide scale use.

Developing the rough diagram is an iterative process. Newitt points out that it is obviously easier, infinitely less costly, and considerably less traumatic to erase a pencil mark during planning than it is say; to remove reinforced concrete during construction. As Newitt advises, the rough diagram usually requires a few drafts with the initial version resembling "a bowl of spaghetti" (Newitt 2009). The first iteration may include backward arrows, logical loops, and inserted activities. Durations are added to the activities once the logic is corrected and the rough diagram drawn more neatly. Special notations can be included and the logic can be traced easier. At this point, entering the diagram into the computer is a fairly simple process, which can be performed by an assistant or staff person. If the network logic is developed on the computer, the scheduler must input the information. This eliminates or at least reduces input from other team members. If the logic diagram is developed manually on paper; critical, the management team engages in deep thinking and learning. The result is more meaningful, detail planning. As stated, the author strongly concurs with the belief that thoughtful planning is a key to project success. Development of the logic diagram is a planning process, not a scheduling process. Once the logic and durations are entered it becomes a scheduling process.

3.6.4 Formulating Logical Relationships

The rough diagram assembles all of the activities required to complete the project. The activities are linked by logical relationships. There are essentially five (5) considerations in determining logical relationships. These include physical relationships, resource relationships, quality relationships, safety relationships, and environmental relationships[34]. All of these relationships are important and none should be neglected. The first and most obvious that the team considers are relationships based on physical requirements.

Physical relationships present the order required for transformation in the physical world. The law of gravity and other natural principles dictates physical relationships. Resource relationships link activities with common resource requirements such manpower and equipment. The resource relationships are usually based on crew or party responsible for executing the task. Equipment in the context of resource linkages can include not only machines, but concrete forms, scaffolding, or falsework elements that are used temporarily to execute one activity, then removed and reused on another activity. Quality relationships are those not dictated by physical requirements but are necessary to ensure the finished work meets the required quality criteria. Safety requirements ensure that activities are linked in a manner that promotes a safe work environment during construction. Environmental relationships are those necessary to conform to environmental regulations and permit requirements. They are also necessary

[34] Categorization of relationships in this manner should not be referred to as "types" since Primavera and many authors use type to denote whether the relationship is FS, SS, or FF. This author would prefer to label FS, etc. as "relationship forms" and physical, et al as "relationship types". At this point, FS as a relationship type is the predominant understanding.

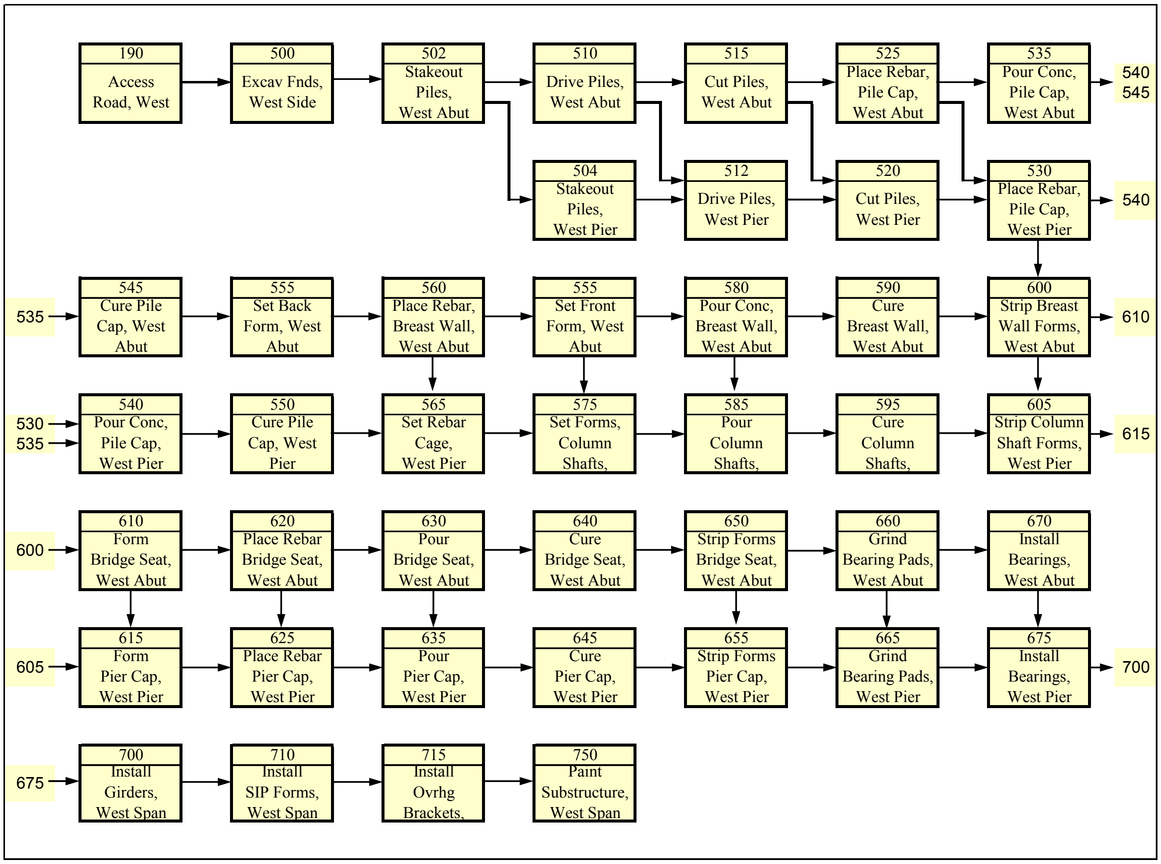


Figure 23 – CPM Schedule of Bridge Construction Sample

to adequately protect the natural and built environment during construction regardless of whether they are mandated by regulation, permit, or specification.

Consider the following example of a portion or fragnet of the work required to construct a new bridge adjacent to wetlands[35]. The fragnet described below and shown in Figure 23 presents the work plan to construct the west span of a bridge. The logic in the example is traced from the bridge girders upstream through the network; that is backwards towards the beginning of the project. Observe that the bridge girders cannot

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[35] A fragnet is a portion or fragment of a network. In this context, fragnets may or may not be part of the critical path; there are other definitions and interpretations. Primavera provides the ability to copy, save, paste, and transfer fragnets.

be installed until the bearings are set in place. The bearings cannot be set until the bearing pads have been ground level to precise elevations. Grinding cannot begin until the concrete pier caps and abutment bridge seats have been cast, sufficiently cured and the formwork removed. However, prior to placing the rebar and formwork for the pier caps and bridge seats, the concrete cast for the pier shafts and abutment breast walls must be adequately cured. Prior to casting the pier shafts and abutment breast walls, these elements must first be formed and the reinforcement bars set in place. Before these steps can take place, the foundations or pile caps must have sufficiently cured after casting. Prior to casting the pile caps, the piles are cutoff to the proper elevation and the reinforcement placed over top of the piles. Of course before that can happen, the piles need to be driven to the required tip elevations. Before the piles can be driven, the structure excavation and subsequent pile stakeout must be completed. The access road must be constructed in accordance with the plan approved by the USACOE in order to gain access to the foundations in a manner least intrusive on the wetlands[36].

Activity 190 Construct Temp, Access Road; West is a predecessor to Activity 500 Excavate Foundations, West Side. An environmental relationship exists between Activities 190 and 500 since the successor depends on the predecessor to meet the regulatory requirement to minimize impact on the wetlands. The Temporary Access Road is not required to physically gain access since that can be accomplished using timber mats. Access may even be possible using low-pressure crawler equipment minimizing the need for mats. However, the environmental permits governing the project require a temporary access road built on geotextile fabric follow by a 3’ (36”) layer of

[36] The United States Army Corps of Engineers (USACOE) maintains regulatory jurisdiction over wetlands and construction work performed under the 404 permit.

wood chips topped with a 1' (12") layer of clean ¾" crushed stone. Aside from regulatory compliance, the temporary access road will do less damage to the wetland vegetation than direct equipment contact or timber mats. Once the temporary road is removed, the original ground and vegetation will rebound much quicker than if scarred by equipment tracks and timber mats.

A physical relationship exists between Activities 500 and 502 since the successor *Stakeout Piles; West Abutment* is physically dependent upon the *Excavate Foundations, West*. Activity 502 is a predecessor to 504 and 510. A physical relationship exists between 502 and 510 since the excavation must be completed in order to allow the piles to be driven for the West Abutment. A resource relationship exists between Activities 502 and 504 since the survey crew that will stakeout the piles for the West Pier must first stake out the piles for the West Abutment. While Activity 500 *Excavate Foundations; West* must be complete in order to begin Activity 504, it is not necessary to link the two since Activities 502 and 504 are linked and Activity 502 is downstream of Activity 500. A link between Activities 500 and 504 is superfluous. However, this pattern changes immediately downstream. Activity 504 shares a physical relationship with Activity 512 *Drive Piles; West Pier*, while Activity 510 *Drive Piles; West Abutment* shares a resource relationship with Activity 512. This pattern repeats several times downstream until Activity 700 *Install Girders; West Span*. The activities associated with the West Pier construction not only have the obvious physical relationships required by the laws of gravity and space, they must wait for the crews to finish similar work for the activities associated with constructing the West Abutment. In other words, the pile crew must finish driving the abutment piles before moving over to drive the piles for pier. This dependency is depicted as a resource relationship and repeats in similar fashion for the activities that require the same crews to complete the work on the abutment and pier.

A physical relationship exists between Activity 535 *Pour Pile Cap; West Abutment* and Activity 545 *Cure Pile Cap; West Abutment*. Obviously, the pile cap cannot cure if the concrete for the pile cap has not been cast. However, a quality relationship exists between Activity 545 and Activity 555 *Place Back Form for Breast Wall; West Abutment*. While the pile cap could physically support the forms before expiration of the cure time, the project specifications require that the concrete be allowed to cure for a minimum of 3-days before applying any loads. Good practice also dictates that concrete should be allowed to gain sufficient strength and hardness prior to any loading. Notice that there is no resource relationship between Activities 545 and 550 since there is no crew dependency. Neither is there a physical or quality connection between the two.

Activities 710 *Place SIP Forms; West Span* and 715 *Install Overhang Brackets and Forms; West Span* are predecessors to Activity 750 *Apply Epoxy Coating; West Substructure*. Activity 750 has physical and quality (for curing) dependencies with upstream activities, but these are transcended by the safety relationship between Activities 715 and 750. There is an overhead danger posed to the crew tasked with painting the West Abutment and Pier until the bridge deck area on the West Span is closed in by stay-in-place (SIP) pans and overhang forms. While the concrete must be cast and sufficiently cured to allow epoxy coating, it is not safe for the painting crew to work on the western substructure until the forms are in place on the superstructure.

3.6.5 Major Subparts

Activities for construction projects can also be categorized into what some refer to as "Major Subparts"[37]. The 5 Major Subparts for a construction project include:

- Mobilization & Demobilization
- Engineering & Procurement
- Owner Activities
- Construction Activities
- Completion and/or facility start-up activities

Comprehensive construction schedules for projects of even marginal magnitude and complexity generally include all five (5) subparts. Construction activities are those involving transformation or conversion. Construction activities appropriately receive the greatest attention and detail, but neglecting the other subparts results in an inaccurate and ineffective schedule and ultimately leads to project failure.

Mobilization includes any activity to establish and secure the jobsite. Demobilization includes those activities associated with formal withdrawal from the site. Two conditions must apply in order to include mobilization and demobilization as schedule activity. First, it must be an effort that has to occur during the project duration. Obviously work that is needed or performed prior to t = 0 (Start Construction milestone) or after t = f (Construction Complete milestone) is not included in the schedule. Second, the activity must be linked to a dependent successor in one the five relationships discussed in the previous section. There is no point of including activities, which are not

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[37] Activities categorized in this fashion are not synonymous with "activity type". Primavera and other authors define "activity type" differently. Primavera requires activity type assignments to control how an activity's duration and dates are calculated.

depended upon by subsequent activities or ultimately project completion. A basic guideline to developing a schedule: include everything that needs to be done in order to complete the project, and anything that could possibly affect the time required to complete the project. Exclude anything that does not meet these criteria.

Mobilization may include establishing a field office or trailer; transport and erection of construction plant such as a concrete plant, hotmix plant, portable generating plant, etc; installing fencing and other security measures required before major work can begin. Mobilization and demobilization of crews and equipment occurs routinely throughout the project execution phase. These moves are typically implicitly incidental to the associated construction activity rather than elucidated as a separate activity. This applies to equipment that is usually shipped in one piece or just a few pieces and is ready for action upon offloading at the site. As an example, hotmix paving activity durations should include the time required to mobilize the crew(s), paving/spreading/finishing machines, and rollers (compactors). If a particular paving operation is estimated to require 4 working days (WD) to complete, but requires 2 days to mobilize after notice, the estimated duration should be 6 WD. There is no need to consider demobilization since it has no impact on downstream activities. In organizations where resources are tracked across the enterprise, demobilization is viewed as mobilization to the next project or statused as idle or available.

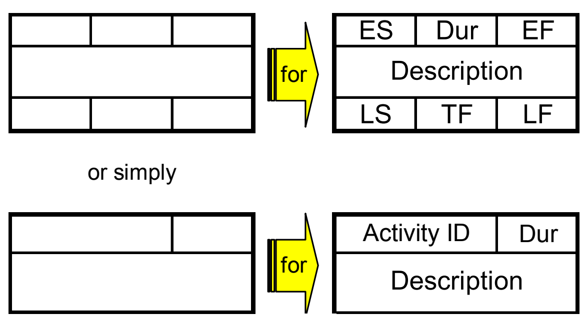

Figure 25 – Activity Box Examples

On the other hand, some equipment may be transported in several pieces on multiple trucks or barge loads and require a significant assembly effort on the jobsite. That type of mobilization should be presented as separate activities in the schedule. For instance, Portland Cement Concrete (PCC) slipform paving requires a paving train of large equipment that must be transported to the site, assembled, calibrated, and must perform multiple dry runs before paving can begin. The associated work should be depicted as discrete activities based upon the required processes and resources. These activities could be offsite as well as onsite. The important consideration is their relationship to downstream activities.

Engineering and procurement activities are vitally important to the flow, quality, and safety of a construction project. These activities are generally conducted offsite and are somewhat inconspicuous. There is sometimes a tendency to overlook or not fully consider these crucial elements, resulting in serious implications for the project. Instead, all engineering and procurement functions required to complete the project must be meticulously detailed and expressed as schedule activities. Engineering activities include all of the requisite tasks associated with shop drawings. This includes preparation, submittal, review and approval process, and final distribution of shop drawings. Each should be presented in the schedule as an individual activity. Engineering submittals also include catalog cuts, material or equipment samples, supporting calculations, and material certifications. Onsite activities are often highly dependent upon these activities. Engineering activities also encompass onsite actions such as construction of mockups and quality control-quality assurance tasks.

Schedule procurement activities are generally those that require lead-time. Lead-time is the span from the point in which an order is placed for goods or services to the point when they are delivered to the site. Clearly, the earliest time displayed by any activity including procurement activities is t = 0. Order origination and lead-time prior to the start of construction is not displayed in the schedule. Only the lead-time forward from t = 0 is included in the construction schedule. Procurement activities often follow engineering activities. Shop drawing preparation, review, and distribution is often followed by offsite fabrication. The example in Figure 24 shows the engineering activities associated with shop drawing preparation and processing for structural steel followed by the procurement activities of “Place Mill Order” and “Fabricate Steel”. The engineering activities of performing the metallurgical testing and preparing the material certifications are incidental to Place Mill Order and shop inspection and testing welds is included in the Fabricate Steel activity. Note that the onsite engineering activity of “Torque Test Bolts” follows the construction activity “Erect Steel”. Someone performs testing in the field other than the ironworker erection crew or the steel subcontractor. Testing the bolts in the field is not incidental to erecting the steel. It is a discrete activity, which must be managed by the project team. While testing welds in the shop is performed by an entity outside of the steel fabricator’s organization, it is usually the fabricator’s responsibility to schedule and coordinate the testing agency’s work. It is generally not the project team’s responsibility to manage testing in the fabricator’s shop, but it is their responsibility to coordinate testing and inspection in the field.

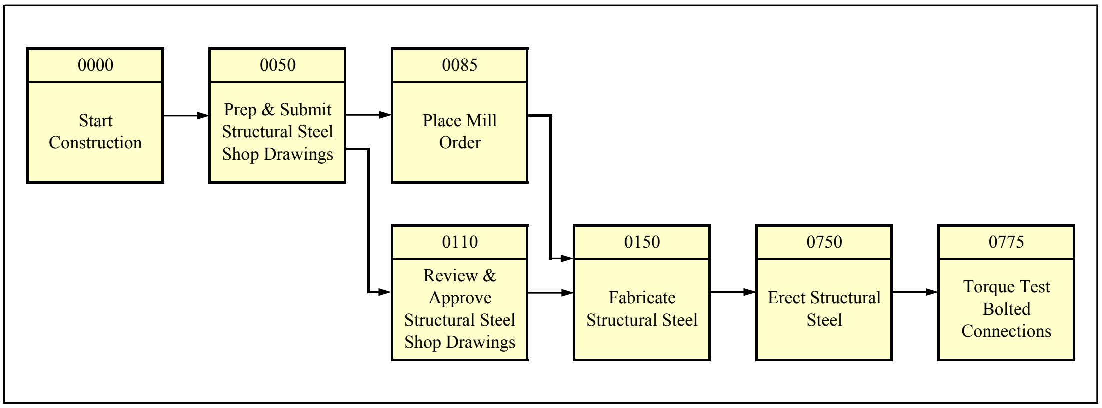

Figure 24 – Shop Drawing Flow for Structural Steel Depicted in CPM Schedule

Owner activities can include obtaining the necessary permits and procuring right-of-way provided that the process overlaps the construction period. Preconstruction activities are those that occur prior to the start of construction or t = 0. Most owner activities are or at least should be executed during the preconstruction phase. However, some owner activities cannot be completed prior to the start and certain must be completed during the execution phase. Some of these activities include the lead-time for owner-supplied material. Owner activities can include a review and approval process that may be beyond the scope of what is expected from an engineering activity. Bank draws and payments upon which downstream activities are dependent are important owner activities. In short, anything the owner must do or provide in order to advance and complete construction between t = 0 and t = f should be embedded in the project schedule.

Completion or startup activities are those that are not necessarily conversion or transformation, but are necessary to complete the project. These activities occur towards the end of the project. Closeout tasks such as semi-final inspection, punch list, removal of temporary facilities, cleanup, and final inspection are examples of completion activities. Start-up, often referred to as commissioning, varies with the type, size, and complexity of the facility. Commissioning of commercial and institutional buildings includes testing and balancing HVAC and hydronic heating and cooling systems. It also includes testing and certifying power systems, life safety systems and devices, communication systems, elevators, electronic door activation among others (McCarthy 2010). Commissioning for bridge and highways projects includes testing and adjusting: signalization, Highway Traffic Management Systems (HTMS), toll management systems, weigh stations, and other activities required to promote the smooth, safe flow of traffic. Training operations and maintenance personnel for any type of facility is also part of the commissioning process. In summary, any activity or milestone required to complete the project within the overall project duration must be properly incorporated and linked in the schedule.

3.6.6 Drafting the Rough Diagram

Network diagrams should always begin with a single initial or "start" activity and end with a single terminal activity or start/finish milestones. The network can be drafted freehand onto various types of media. A roll of paper or even butcher wrap will suffice. The blank side of old full-size plans sheets; those from previous projects work well. 11" x 17" copy paper is convenient from which to enter the rough diagram network into the computer since a stack of sheets fits nicely along the workstation. The downside is that 11" x 17" paper only fits 25% of the information that can be placed on a "D" size plan sheet which is typically 24" x 36" or 22" x 34". The D-size sheet facilitates team planning since construction professionals are accustomed to gathering together around a set of plans. Placing the current plan set along side of the sheets upon which the team is drafting the rough diagram is particularly handy. Using a roll of paper allows the diagram to be drafted continuously, but using individual sheets requires incorporation of adequate match line notation.

While ADM can be use to draft the rough diagram, most commercial scheduling software uses PDM, which of course is AON-based diagramming. Therefore, it is more efficient to employ AOA methodology for drafting the rough diagram[38]. An alternative to drawing nodes or activity boxes freehand is to use a rubber stamp and inkpad. Another alternative is to print the activity boxes onto addressing or file labels such as those produced and packaged by Avery®[39]. Customized activity box templates are prepared using Microsoft® Excel® or the "Table" option in Microsoft® Word® and printed onto 8½" x 11" sheets of labels on an inkjet or laser printer. 1-1/3" x 4" address labels such as Avery® 5962, 8462, 8462, 5662, and others are packaged 14 per sheet. Activity boxes can have any configuration such as those shown in Figure 25. The author prefers a simpler activity box configuration that merely includes an Activity ID, Activity Description, and duration. Another method is to use Post-it®[40] notes on which the activity boxes can be printed then later scanned and imported into Primavera. 3" x 5" index cards are an older medium for activity boxes, initially popularized by the Gilbane Building Company by what is coined "The Gilbane Card Trick".

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[38] Some "old-timers" still prefer using AOA or ADM since they are most accustomed or comfortable with the arrow graphics. This is one of the reasons that colleges/universities continue to teach or at least introduce students to ADM along with in-depth instruction on PDM, even though the former has long since grown outdated.

[39] Avery Dennison Corporation

[40] Post-it® Brand sticky notes are a product of 3M Corporation

3.6.7 Gilbane Card Trick

The Gilbane Card Trick is a methodology of developing a schedule in a team environment, first attributed to the Gilbane Building Company. Today, many organizations employ an approach that is at least similar to the Gilbane Card Trick, often using Post-it® notes. Different colors are used for preliminary coding to indicate trade or subcontractor affiliation. Color-coding facilitates visualization and expedites development of the network. The process typically begins with a pre-card trick (preconstruction) meeting in which the project manager presents an overview of the scope and introduces the team to the general contractor/CM's initial approach to the work. This typically precedes a workshop that engages all team members. During the initial meeting, a facilitator describes the scheduling process, parameters, and expectations. The participants agree to a general approach to the project. While the facilitator is a role sometimes filled by the scheduler or project manager, some argue, especially consultants, that the facilitator should be an independent party that can address difficult issues without brining bias into the discussion. An independent facilitator may be in a better position to keep the planning process moving forward and to ensure that it is truly collaborative. He or she serves as at once as a coach, referee, champion, and arbitrator. It can be difficult at best for an internal team member to simultaneously execute these roles and remain objective.

The next step after the initial meeting is for the individual firms, i.e. prime contractor(s), subcontractors, design teams, fabricators, and other team members to complete the cards. Each party prepares cards (one per activity) for all of their activities, which list their work with duration, predecessor and successors if known, resources, constraints, and any special notations. The project leadership team simultaneously prepares for the planning workshop. While not mandatory, a time line calendar can facilitate network development. A continuous timeline can be drafted onto a roll of paper and hung on the walls of the meeting room. Some "war rooms" are surrounded by whiteboards upon which the timeline can be drafted. Upon reconvening, the facilitator leads the workshop, instructing the participants to sequentially place their cards on the timeline; generally starting from the ground up for building and bridge construction or clearing operations for horizontal highway construction. The facilitator connects the activities; effectively assembling the logic diagram. The facilitator identifies gaps, overlaps, or false assumptions. The Team reviews and revises logic as necessary after which the logic diagram is entered into the computer without developing a new or different schedule. The computer output is plotted and senior project leadership reviews the resulting network. Senior leadership may identify and suggest revisions to the network in an effort to make the schedule fit the designated time specified in the contract documents. Additional workshop time may be needed at that point to further refine the schedule. Once the leadership team is satisfied that the schedule is viable and workable, a follow up or "post-card" trick review meeting is held to obtain final buy-in from across the entire team. Final buy-in is crucial in that it reinforces the team's understanding of the work requirements. More importantly, it reaffirms the team's ownership of the schedule. As previously noted, personal ownership of the schedule ensures a greater commitment to its successful execution. Individuals are naturally more inclined to adhere to a schedule that they helped create as opposed to one which is dictated or forced upon them.

3.6.8 Activity Durations

The amount of time or duration required to complete the activity is never truly known until after the work is complete. Scheduled work is based on duration estimates. CPM uses a single discrete duration estimate for each activity, unlike PERT, which uses probabilistic methods to estimate duration. Duration estimates are completed one activity at a time, initially assuming required resources are available. Other initial assumptions include normal level of manpower and equipment and a normal workday[41]. It is important that the team and/or scheduler not try to fit the activity in a perceived available time. The scheduler should work closely with those familiar with the type of work in estimating durations. Better yet, those charged with actually performing or managing the work should have direct input in estimating activity durations, a reoccurring theme thus far in this thesis.

There are a number of ways in which to estimate durations. One approach is to base durations on estimated production rates. In this approach, the estimated quantity of work is divided by an estimated production rate to yield an estimated duration. Consider for example the activity "Drive Piles, East Abutment", which requires that 28 piles be driven at the specified location. The estimated pile length is 45' from tip to cutoff. The total length of driven pile is 28 x 45' = 1,260 linear feet (lf). The estimated production rate = 70 lf/hr. Therefore, the estimated duration is 1,260 lf ÷ 70 lf/hr. = 18 hrs. = 2.25

[41] May or may not be an 8-hour work day. It depends on the organization's standard work day, which may be 10 hours or more.

days. Allowing some time for setup and cutting piles, the estimated duration = 3 days. Estimated production rates can be obtained from various sources, but typically the most reliable source is the company's historical records.

Companies generally maintain a comprehensive database of costs from previous projects. Prudent organizations compile records based on labor hours often in the form of man-hours or crew-hours. Production rates from similar work on previous projects are extracted and adjusted to suit the conditions at hand. While the proposed work may be similar in nature to that completed for previous projects, there may be certain constraints or other circumstances that are different. Thus, historic production rates cannot be used without due consideration of the work situation and tempered accordingly. Whereas historical records are quite valuable, the author does not recommend blindly depending on as-built schedules as source from which to base estimated durations. As-built schedule data may or may not provide adequate insight into the actual duration required to complete an activity. Analogous time estimates may not be valid. The AS and AF merely reflect the time an activity started and finished. How closely does the quantity and nature of the previous project activities align? Care and due diligence must be applied in answering these questions. External sources such as Means or Walker provide production rate data[42]. Again, care must be exercised in using the information. Regardless of the source, experience and judgment are indispensable when it comes to estimating activity durations.

Another method of estimating activity durations derived from internal sources is the expert judgment of superintendents and other similar experienced professionals. The

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[42] RSMeans Cost Data published by Reed Construction Data® and Walker's Building Estimator's Reference Book, 28th edition published Frank R. Walker Co.

advantages of utilizing internal expert judgment include the expert's intimate knowledge of the work, familiarity with the company's approach to the work, and desire to see the successful completion of the planned work. One the drawbacks of relying on internal experts includes the lack of depth in analyzing the proposed work. Even seasoned professionals should avoid off-the-cuff estimates. The benefit of estimating durations utilizing production rates is that it requires a certain depth of thought and formal analysis. Duration estimates of small, simple tasks can be estimated much quicker and perhaps even more accurately through expert judgment. However, larger more complex activities require deeper evaluation and substantiation. That being said, the value of expert judgment must never be under appreciated.

A major pitfall of extracting production rates or durations from team members is the inclination to inflate estimates to reduce their individual risk of overrunning the allotted time. Such behavior results in longer project duration or disproportionately higher risk for other team members. The inclination is a normal human characteristic that varies according to one's propensity towards or aversion to risk (Hardman 2009). Team leadership must be aware of this potential and work to minimize inflated estimates. To counter this behavior, leadership must employ team-building techniques that promote mutual trust. The need to fairly and evenly distribute risk must be engrained within the team's DNA such that it becomes part of its culture.

Even with the best intentions and honest effort, some individuals are influenced by a cognitive bias. Cognitive biases can take many forms and result from many factors. The term "cognitive bias" refers to various distortions of the mind causing faulty judgment and imprecise perceptions (Virine and Trumper 2008). Such biases can be negative or optimistic. Team members that exhibit these biases may routinely over or under estimate production rates or activity durations. The scheduler may be able to compensate for bias provided that there is a recognizable pattern of deviation. For instance, if a team member brings an optimistic bias, they will have a tendency to over estimate production rates or under estimate durations. A perceptive scheduler (project manager) through empirical observations can detect and quantify patterns of deviation. If a team member's honest estimates routinely overrun the actual durations by an average of 25%, the scheduler can adjust future estimates by a factor of 1.25. Effective, reliable scheduling mandates that planning is performed in a collaborative team environment, in which the team's leadership can discern the quality of estimates and recognize patterns of deviation.

External sources of duration information include that provided by subcontractors, fabricators, suppliers, utility companies, and anyone that must provide materials, components, or services in order to complete the project. The argument for collaborative planning has been made repeatedly to this point. Subcontractors, suppliers and the like are often considered external project team members; but team members nonetheless. Input from external members regarding durations of their activities is vital for all of the various reasons stated thus far. However, an inherent problem with using unvetted durations given by subcontractors is the tendency (often greater than internal members) toward inflated time frames asserted to reduce their risks.

3.6.9 Establishing and Managing External Durations

Various strategies and tactics can be effective in managing subcontractors' and vendor's time commitment and performance. While the project management team must include these external members in the planning process, it is vital that they be kept honest throughout procurement, planning, and execution phases. Time management of subcontractors and vendors begins in the procurement phase. Typically, the GC/CM solicits bids from subcontractors and vendors to supply or complete various components of the project[43]. The unfortunate truth of the matter is that selection is often based strictly on the lowest price. This practice does not necessarily translate into best value. Too much emphasis is placed on cost while neglecting other important elements of time, quality, and safety.

The management team must routinely employ certain procurement practices when it comes to soliciting bids and negotiating subcontracts. First, the project manager and other internal team members having significant interface with subcontractors must acquaint themselves with the scope of the work being subcontracted. Certainly, a general contractor is not likely to possess the understanding of the specialty subcontractor, but experienced construction professionals should have a basic understanding of the specialty work. The prime contractor that does not fully apprise themselves of the subcontractors's scope of work prior to letting is operating in ignorance and is in a position of disadvantage. One cannot reasonably approximate duration requirements without at least

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[43] The term "prime contractor" refers to the construction organization that is contractually bound to the project's owner to complete all or part of the work. Prime contractors subsequently contract with specialty contractors to complete a portion of the work. This is referred to as "subcontracting" and is standard operating procedure in the construction industry. While not completely accurate, the term prime contractor will be used interchangeably with GC/CM in which the CM is at-risk contractual arrangement.

some understanding of the depth and breadth of the work. Step 1 in keeping subcontractors honest is for the contractor to know exactly what is required in terms of deliverables and have at least some understanding of the connected processes, resource requirements, and challenges.

In many situations if not most, it is not reasonable to expect a subcontractor to fully engage in planning with the project team prior to executing the subcontract agreement. However, prudence dictates that the prime contractor secures certain time commitments from the subcontractor prior to executing the subcontract. The procurement process must extract time and resource commitments from subcontractors, not merely prices. Proposals from potential subcontractors must be evaluated for time considerations as well as price. This is Step 2 in keeping subcontractors honest. Proposed durations as well as prices can be evaluated across the pool of prospective subcontractors. After which, terms of the subcontract must include maximum durations for the various portions of the work, time frames of availability, and the resource levels upon which the subcontractor bases these time commitments. A contractor loses leverage once the subcontract instrument is executed[44]. Therefore it is in the prime contractor's best interest and ultimately that of the project to include time considerations in subcontractor selection criteria and include specific time and resource commitments in the subcontract agreement.

Once the subcontractor is on board, that is a subcontract with the prime contractor is in place, the subcontractor should be included in the planning process with rest of the

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[44] Leverage in this context is derived form contractual, legal obligations. True partnering and the Integrated Project Delivery (IPD) paradigm neither embrace nor rely upon this type of leverage to motivate external team members.

project team. This is Step 3 in keeping subcontractors honest. This heightens learning and understanding for the entire project team, including the subcontractor. It also fosters team building and enhances communication; the value of these two functions should not be underestimated. Spoken commitments or "promises" made in a team setting can also be powerful devices towards ensuring timely execution of the work. The power of promises can be quite substantial. Team members that routinely or indiscriminately break their promises should not be invited to bid on future projects.

Step 4 in keeping subcontractors honest is by first being honest with them. A prime contractor should never intentionally misinform a subcontractor of the true requirements, projected progress, etc. Team leadership should instead be honest with subcontractors and never "cry wolf"[45]. Such behavior is counterproductive to team building and leads to legitimate calls for help going unheeded. The author believes that even when dealing with unreliable subcontractors, the prime contractor should never lie or mislead. However in this case, being honest does not mean being completely open and transparent with these unreliable players. Tactics employing schedule mechanics to shield downstream activities and the project itself from unreliable subcontractors is in fact appropriate when warranted. These tactics include displaying early boundary dates and not revealing the float associated with a particular chain of activities. Another means of shielding downstream activities from unreliable subcontractors who routinely exceed their duration commitments is to utilize positive lag in a FS relationship between the offending sub's activity(s) and successor activity(s).

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[45] To "cry wolf" is a figure of speech derived from the fable attributed to Aesop *The Boy Who Cried Wolf* meaning to "raise a false alarm" or "call for help when it's really not needed"

As an example, an electrical subcontractor has committed to complete installation of a certain duct bank in 15 working days. The duct bank is the predecessor to placing graded aggregate base course in that same section of proposed roadway. The prime contractor has a sense that the subcontractor is not seriously committed to completing the duct bank in 15 working days, but will most likely finish the work in 20 days; 5 days late. The scheduler could place a 5-day lag in between the duct bank installation and placement of graded aggregate base course. This is preferred over increasing the duration of the duct bank installation. Doing the later; that is increasing the duration to 20 days in effect gives the electrical subcontractor a license to finish the duct bank in 25 days. As displayed in Figure 26, the ES of the base course placement is the same whether there is a 15-day duration for the duct bank with FS = 5 as there is when the duration = 20 days where the FS = 0. This fact is not readily apparent to the offending subcontractor who only sees the 15-day duration in which they have committed to complete the duct bank.

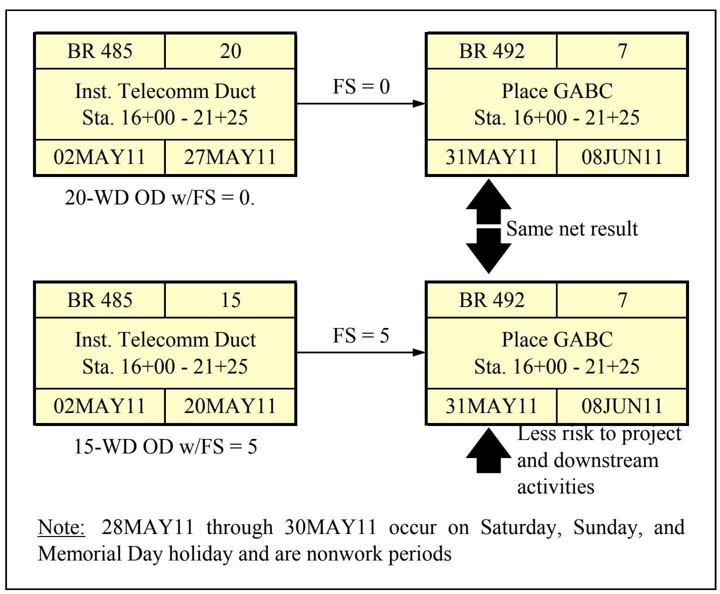

Figure 26 – Use of Lag

Step 5 in keeping subcontractors honest is not really a single measure, but an approach to dealing with all project team members that should be standard mode of operation. It is unfortunately far from standard practice in any segment or division of the construction industry. The prime contractor should keep all subcontractors informed of progress and advised of when they are expected on the site and just what is expect of them. Instead, prime contractors often fail to regularly communicate with subcontractors habitually subjecting them to eleventh-hour notices and last minute demands. Specialty subcontractors are all too frequently subjected to this type of treatment. The result is that subcontractors are not able to make reliable work plans, nor optimize efficiency or performance. This of course translates into unreliable planning and inefficiency for the project. Project planning reliability is limited by the

Table 3 – Guardrail Installation Schedule

GREGGO & FERRARA, INC.

CHURCHMANS ROAD & SR7 INTERCHANGE
REHAB OF BRIDGES 716, 716A, & 717 I-95 OVER SR7
CONTRACT 91-101-04/96-074-02

GUARDRAIL INSTALLATION SCHEDULE

No.[3]	Location	Sht. No.	ES/LF[4]	Approximate Quantities/Comments
1	Churchmans Rd. Median 11+438 to 11+500	66	8/23/99-10/1/99	81m GR, 4m median barrier beam, 2 - CAT 350
2	Churchmans Rd. Median 12+197 to 12+263	69A	8/23/99-10/1/99	86m GR, 4m median barrier beam, 2 - CAT 350
3	Churchmans Rd. Median 12+409 to 12+461	69A & 70A	8/23/99-10/1/99	84m GR, 4m median barrier beam, 2 - CAT 350
4	Frontage Rd. 22+134 to 22+178, Lt. SR7	62 & 63	8/23/99-10/1/99	2 - ET 2000, 15m GR
5	Frontage Rd. 22+404 to 22+447, Lt SR7	63	8/23/99-10/1/99	2 - ET 2000, 15m GR
6	NB SR7 22+385 to 22+440, Rt.	63	9/20/99-10/1/99	1 - ET 2000, 36m GR
7	NB SR7 21+413 to 21+436, Rt.	60A	9/20/99-10/1/99	1 - ET 2000, GR to barrier connection (approach)
8	AAA 33+033 to Service Rd. A 9+670, Rt.	62		2 - ET 2000, 34m GR incl. Thrie Beam attached to HW
9	NB SR7 21+810 to 21+920, Rt.	61 & 62	9/20/99-10/1/99	1 - ET 2000, 91m GR
10	Ramp C 0+270 to 0+310, Lt.	62	9/20/99-10/1/99	1 - ET 2000, 21m GR
11	NB SR7 21+694 to Ramp B 0+300, Rt.	60A,61,68,71	9/20/99-10/1/99	1 - GR to barrier connection (exit), 212m GR
12	Ramp B 0+110 to 0+190, Lt.	61 & 71		1 - ET 2000, 68m GR
13	Churchmans Rd. Median Br. Pier to 11+889	60A	9/20/99-10/1/99	1 - CAT 350, 9m GR, 2m med. barrier beam 1 - GR to barrier connection (exit)
14	SB SR7 22+730 to 22+800, Lt.	65	10/4/99-11/12/99	1 - ET 2000, 51m GR
15	SB SR7 21+690 to 21+835, Lt.	60A & 61	10/4/99-11/12/99	1 - ET 2000, GR to bridge conn. (approach) 124m GR
16	Ramp A 1+200 to 1+231, Lt.	61	10/4/99-11/12/99	31m GR, 1 - Buried End Section
17	SR7 Median 21+200 to 21+280	59	4/1/00-5/1/00	1 - GR to barrier connection (exit), 76m GR

Notes:

1) The table shown above is the tentative schedule for Guardrail Installation required for this project. The schedule is based on the current workplan and is subject to change. This schedule will be updated from time to time to show current status.
2) Quantities listed are approximate and must be checked against the plans and/or verified in the field.
3) The Number in Column 1 represents the priority order of guardrail installation.
4) Dates in the ES/LF column are the early starts and late finishes at each location, and indicates the approximate window to complete the installation.

reliability of the supply chain. The prime contractor can increase subcontractor performance through proactive communication. Regular communication must be maintained from the initial planning phase through final execution and acceptance of the work.

Table 3 shows a table titled “Guardrail Installation Schedule” generated by a prime contractor for the specialty sub, which lists requirements for a project in priority order. The schedule specifies the location, approximate quantities, and estimated boundary dates. It also indicates on which plan sheet the particular installation can be found. Why are plan sheet references included? The prime contractor’s project manager is intimately familiar (or certainly should be) with the contract documents including the construction plans. A specialty contractor likely deals with dozens or even hundreds of project plans in a year. Anything that the prime contractor can do to expedite and heighten the subcontractor’s learning and understanding of the project is certainly in the best interest of both parties and can increase reliability and the likelihood of project success. Of course, the schedule must include the appropriate disclaimer so that the subcontractor is not relieved from performing its due diligence. It also should be updated regularly to reflect progress and the current work plan and distributed to the subcontractor. A schedule of this nature is an excellent communication tool, but it must be supplemented with emails, telephone calls, and face-to-face meetings as warranted. In many instances, nothing is as effective as a real time person-to-person conversation. However, those conversations must be on going and timely in order to be effective.

The best approach to effective time management across the project is to build and maintain a strong supply chain. The team must consist of internal and external players that are committed and dependable. Reward team players for superior performance. These rewards do not have to be purely financial but can be some act of recognition for commitment and excellence. Best-in-class organizations reward both internal and external team members for excellent performance (Newitt 2009). It is important that team leaders understand and apply basic motivational practices. Maslow and Herzberg espoused human behavioral theories regarding motivation, which have been validated several times over and widely embraced in the business world (Gawel 1997). Maslow's Hierarchy of Needs includes "esteem" as a type of need. Esteem in this context can be defined as self-respect and the respect of others. Herzberg's theory of motivators and hygiene factors are those affecting a person's attitude towards work. Maslow defined hygiene factors as those that can create dissatisfaction when below perceived acceptable levels but do little to motivate workers when exceeding expectations. Hygiene factors include company policy, supervision, interpersonal relationships, working conditions, and salary. Hygiene factors effectively serve as a platform upon which to build motivation as depicted in the rocket analogy depicted in Figure 27. Herzberg demonstrated that certain motivational factors enhanced the long-term performance of employees. Strong motivational factors include achievement, recognition, the work itself, responsibility, and advancement. The degree of applicability of Maslow and Herzberg to groups and to those working in construction may vary in congruence to the pure theories and is in fact a point of discussion and research (Ruthankoon and Ogunlana 2003). Regardless, the author suggests that there is ample evidence to support the value of applying Maslow and Herzberg theories to practice in construction[46].

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[46] No theory can perfectly model behavior due to the extreme complexity of humans. The author suggests

Again, it is vitally important that team relationships are based on trust and fair treatment. While every team member must be accountable for timely execution and fulfilling commitments, no one should be subjected to mismanagement or laissez-faire coordination. Good scheduling practices dictate that two or more crews are not scheduled to work in the same area simultaneously if space constraints are not sufficient to do so (Newitt 2009). Neither should the same crew be scheduled to be in two or more places at the same time or slated to execute simultaneous activities. A cardinal breach of team trust is to request or assign crews to work before the site is ready for them. Such behavior destroys trust and builds resentment. Nothing needlessly taxes a subcontractor more than pulling crews from a job on which they are working productively and mobilize to another project that is not ready for them.

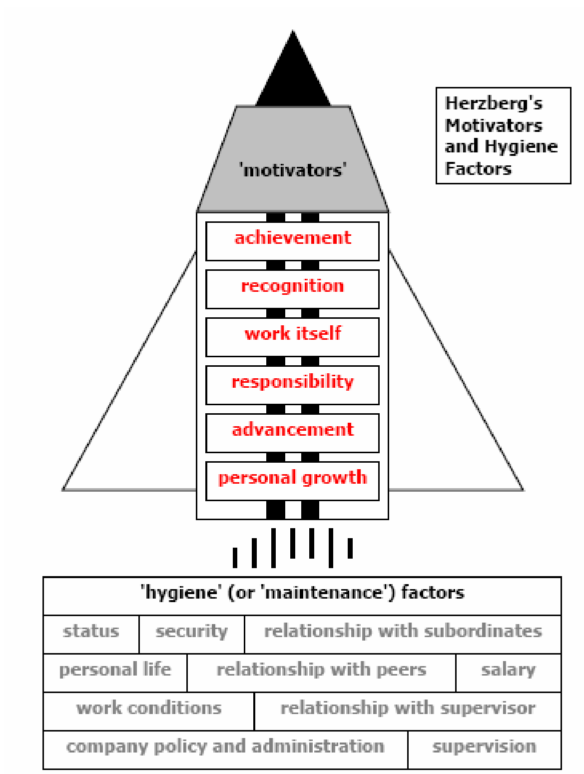

Figure 27 – Herzberg's Hygiene Factors

The subcontractor incurs direct and indirect costs that are usually unrecoverable. The direct costs include the wasted demobilization from the initial job, mobilization to the new job, and remobilization back to the initial job. Indirect costs include the loss of continuity and momentum on the initial job, the wasted coordination effort, and extended overhead.

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that Maslow and Herzberg are sufficiently reflective of human behavior and suitable for application in leadership practices.

There is a ripple effect with ramifications beyond these initial costs and wasted effort. Consequences often extend to the offending prime contractor and the project. The frustration and diminished trust suffered by the subcontractor translates into reduced commitment, tolerance, and honesty towards the prime contractor. The subcontractor's concern for and dedication to the project's overall success is reduced and is eventually shattered by repeated breaches. The subcontractor's sense of team is weakened and ultimately destroyed. The subcontractor has no care or concern for any of the project stakeholder. There is no longer a willingness to share the risks associated with the project. These negative reactions are unproductive at best, but tend to actually be destructive. The most unfortunate aspect is that this is all avoidable. Not to oversimplify, but these problems can largely be avoided by following the Golden Rule; treat others in a manner in which you wish to be treated. Of course it also takes proactive tracking, impeccable coordination, and effective communication. However, projects and their stakeholders suffer when honesty and integrity are missing.

3.6.10 Monitoring, Updating, and Revising Schedules

Monitoring or tracking activities and updating the schedule once the work begins are analogous to sharpening drill bits or saw blades. If allowed to become dull, drill bits and saw blades grow ineffective and eventually incapable of performing their intended purposes of boring and cutting. Construction schedules are tools for organizing and managing work. They are tools for formalizing and communicating the work plan to the stakeholders. However in order to be effective, schedules must present an accurate model of the work plan. To be that accurate model, the schedule must be continuously updated to reflect the work plan in its current state. The current state is determined by progress to the data date, the understanding of the work, which has evolved to that point in time, and any combination of factors that cause a schedule to deviate from the original work plan. Maintaining the schedule to reflect the current state through its various life cycles is essential if it is to remain a useful tool. It is also essential that the schedule be kept current to serve as documentation for determining damages or eligibility for time extensions. Whatever the purpose, the schedule must be kept current to realize its full value.

Schedules are kept current through updating or revising the baseline schedule. The definition of the term "baseline" schedule has at least two interpretations. One interpretation holds that the baseline is the original schedule accepted by and agreed upon by the project's primary stakeholders[47]. By that definition, there is only one baseline for the entire schedule life cycle. In some circles, that definition is extended to include original schedules that are revised to reflect a change in scope. The prevailing contemporary definition articulated by Primavera in the current P6 literature is that "A baseline is a copy of the project schedule at any point in time. A baseline will be created when the project schedule is first approved and each time a progress update is completed. Each project can have an unlimited number of baselines (Primavera 2009)." That definition would be more precise if it read "…each time a progress update is completed *and approved*." Approval or acceptance is requisite validation necessary to consider a schedule be a baseline regardless of the life cycle stage. P6 allows the current project to

[47] The primary project stakeholders in this context include the owner and the internal and external project team charged with executing the work. This term is extended to anyone with oversight responsibility mandated by statute, regulatory law, or contract requirement.

be compared against four (4) baseline versions. P3 refers to baselines as "Target Schedules" and provides the capability comparing the current schedule against two (2) targets.

Schedule monitoring involves tracking when planned activities actually start and finish. Monitoring may also include tracking costs and resource utilization associated with construction activities. An organization is almost certain to routinely collect data on costs, resources, and progress on a daily bases. This data collection is accomplished through the foreman's daily report or some similar mechanism. The information is entered into the company's accounting system and used to generate payroll, establish accounts payable and receivable, pay taxes, and feed the organization's historical database. Production rates and other historical information from the database are useful in preparing future cost estimates and construction schedules. Financial and cost accounting can be integrated with project systems that facilitate cost control, which is a function of project management. However, schedule monitoring is usually a separate function from the central financial and cost accounting process just described.

Various methods are used to track schedule activities. The best systems incorporate daily recording that is consistent with but separate from the project journal or diary. Tracking and recording activities on a daily bases ensures accuracy. Gleaning information from daily reports or diary entries to maintain the schedule can be cumbersome. It is much more expedient to utilize a tracking system consisting of a form(s) that is separate from daily journal-type entries. A sample tracking form prepared using Microsoft Excel is shown in Table 4. The advantages of using such a form are that it streamlines the tracking process, can be stored electronically, and is subsequently easy to retrieve. It does not include any extraneous information. Personnel tasked with tracking the activities can manually record the required the data in a clear and concise manner. The information is easily entered from the tracking form into the Primavera schedule database. Making daily entries directly into the Primavera database is neither

Table 4 – Sample Schedule Tracking Form

										Equipment Hours									
Activity ID	Activity Description	OD	RD	AS ☑	AF ☑	WD	Unit	Units Comp	CREW Code										Comments
GF5250	Close Ramp I Aux. Lane	2	2	☐	☐														
GF5072	Temp Sheeting, Wall A (Incl tiebacks)	21	4	☐	☐														
GF5260	Establish E & S, Ramp I	2	2	☐	☐														
GF5270	Clear & Grub, Ramp I	2	2	☐	☐														
GF5073	Excav. for Wall A	7	4	☐	☐														
GF5160	600mm RCP CB 8 to FES 2	2	2	☐	☐														
GF5280	600mm RCP CB 8 to CB 7 to FES 2B	7	7	☐	☐														
GF7045	Initial Wick Drains SR7 21+490 - 21+620	15	15	☐	☐														
GF5290	Excavate/Grade, Ramp I, Rt.	8	8	☐	☐														
GF5300	GABC, Ramp I, Rt.	4	4	☐	☐														
GF5310	C-1, C-2, & GM-1 Sign Str./Fnds.	30	30	☐	☐														
GF5320	U/G Lighting/Traffic Control, Ramp I	3	3	☐	☐														

required nor practical. CPM construction schedules using days as the planning units are not usually updated daily[48]. The frequency of CPM construction schedule updates is usually weekly, biweekly, or monthly.

Updating the schedule consists of statusing, reasonable modifications to logic, applying change orders, and insert or modify coding for better organization in working with and presenting the schedule. More significant changes are usually referred to as Schedule Revisions. Statusing is merely reflecting progress by inputting AS, AF, and

[48] CPM schedules prepared for critical emergency or maintenance projects with short overall durations of a few days may employ hourly planning units. Daily entries and updates may be warranted in such cases. Two examples of CPM schedules utilizing hourly planning units are included in the Appendices of this thesis.

adjusting the RD when the activity was started but not completed prior to the data date. The data date is the point in time to which progress has occurred and from which the remaining work will be scheduled. It is the earliest possible ES. For an original schedule, the data date is t = 0 or the beginning of construction. On an update, the data date is the first day after the period under consideration. For instance, if the schedule is being updated to include all progress through May 2011, the Data Date for that update is June 1, 2011. It considers all work completed through May 31st as progress and schedules the remaining work onward from June 1st. The earliest possible ES for any remaining activity is June 1. Inputting resource consumption and in P6, indicating percentage of completion is also considered statusing.

In P3, Percent Complete is based on duration consumed to date. It is automatically calculated as Percent Complete = (OD – RD)/OD x 100. The Percent Complete calculated in this manner may or may not be representative of the actual progress. P6 and other software produced since the release of P3, v.3.1 employ alternate methods of computing or otherwise defining Percent Complete. P6 has three distinct Percent Complete types including Physical % Complete, Duration % Complete, and Units % Complete. The type set for a particular activity is linked to and populates the Activity % Complete value. The Physical % Complete is a subjective value entered by the scheduler, whereas the Duration and Units are calculated by entering the consumed amounts.

Revising or modifying the schedule is a necessary reaction to change, which often includes modifications to logic to reflect a modified work plan. Revisions are often driven by internal or external pressure to accelerate or regain lost time. A schedule revision represents a material change in the work plan for whatever reason. Any number or combination of factors could necessitate such change in the work plan. Some of these factors include:

- weather
- force majeure including acts of God
- better or worse productivity than anticipated
- delivery problems
- greater insight to the actual scope of work
- subcontractor performance/availability
- change in scope of work
- differing site conditions

Comparison of the current state against a baseline(s) is performed for many reasons. Effective management is impossible without performance measurement. Comparison reveals deviations between the as-planned and as-built condition or a previous as-planned vs. the current state as-planned projection. The value of such comparisons extends to both contemporary management practices and forensic schedule analysis (FSA). Reflective comparisons enable the management team to assess project performance in terms of time and other attributes such as cost, cash flow, resource utilization, and earned value. Time deviations between as-planned and as-built conditions are referred to as schedule variances. Cost variances are measurable in budgets in which the actual costs are compared against budgeted amounts. Cost and schedule variances are measured using various direct and indirect methods that reveal how closely the actual performance matches the planned performance. Earned Value

Analysis (EVA) or Method (EVM) augmented by the Earned Schedule Method (ESM) is an approach presented later in this thesis. While various evaluation techniques provide management with a means of assessing performance from an historical perspective, EVM is also utilized to forecast performance for the remaining portion of the project. The idea is that the need for corrective action is identified and the management team can then take the necessary steps to bring the project in on time and on budget. Contemporary project management practice views this as control. The truth of the matter is that responding to trend projections is reactionary rather than proactive control. This point is reiterated in the critique of the contemporary project management paradigm.

3.6.11 Short Interval Schedules

Effective time management demands detailed, date-specific schedules to better plan, communicate, and execute the work. As a practical matter, the CPM schedule serves as the project's master schedule. It contains boundary dates, which are periodically updated to reflect progress. However, these early and late boundary dates merely present a range in which an activity can theoretically begin and when it theoretically must be finished in order to avoid delaying the project. It does not specifically display the precise dates in which the work will be performed. A short interval schedule can display the exact dates and locations of upcoming activities. This differs from a look-ahead schedule report or display generated in P3 or P6, which merely projects a time range. A short interval schedule is usually formatted as a type of bar chart and is a particularly effective tool for communicating the work plan. It is a detailed schedule of the work planned for the immediate future. The format and content are user-friendly and relatively easy for field personnel to interpret without difficulty.

Short interval schedules typically display a two or three week look-ahead window. Table 5 shows a two-week schedule and Table 6 displays a three-week schedule. The schedules are typically developed weekly, regardless of the look-ahead period. In other words, a three-week look-ahead short interval schedule is developed weekly, detailing the work in the coming week and the next two weeks out (Newitt 2009). It is for this reason that this type of short interval schedule is often referred to as a "weekly schedule" regardless of the span of the look-ahead window since it is prepared and distributed on a weekly basis. Weekly schedules more accurately reflect immediate work plan because actual conditions are more predictable, i.e.: progress, weather, resources, subcontractor availability, short-term goals, and special considerations. A weekly schedule more directly communicates the work plan to the field personnel, explicitly indicating the task and location with the specific dates. Color-coding and annotations clarify or reinforce work plan and enhance the schedule. These enhancements increase the effectiveness of the schedule as a communication tool. The standard form can be further modified to include crew or resource assignments and special directives.

Aside from the valuable output produced, short interval schedule preparation carries the collateral benefit of sustaining the planning continuum. As activities draw closer to actual execution good scheduling requires the support of more detailed planning. Short interval scheduling provides the practical framework for effective planning. It facilitates the Rolling Wave technique, which entails providing more detail to the schedule as the time frame of the work approaches (PMBOK 2008). As with master planning, or perhaps even more so, weekly schedules should be prepared collaboratively with input from those charged with executing the work. This includes the front line supervisors, specially superintendents and foremen. Weekly production scheduling is further enhanced in Last Planner™, which is presented later in this thesis[49]

3.6.12 Milestone or Goal-Oriented Schedules

Like weekly schedules, milestone or goal-oriented schedules are excellent planning and communication tools. Milestone or goal-oriented schedules can encompass more or less detail than the full project CPM schedule. They are based on the CPM schedule, but present the work plan in ways not facilitated by the master schedule. These types of schedules typically display a path or chain of events leading towards attaining a goal or reaching a milestone. Not only are these types of schedules good communication tools, they also contribute toward team building and motivation. As mentioned, milestones serve to compartmentalize projects into more manageable segments or phases, and sets takt time for timely project completion. The schedule form described here is not the same as the milestone schedule incorporated in the Last Planner™ discussed later.

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[49] Last Planner™ is a registered trademark of the Lean Construction Institute.

Table 5 – Two-week Schedule Example (Top) and Table 6 – Three-week Schedule Example (Bottom)

FOR THE WEEK BEGINNING MONDAY, 10/11/99 TO MONDAY, 10/25/99															
ACTIVITY	LOCATION	M	T	W	T	F	S	S	M	T	W	T	F	S	S
Form Removal and Misc. Cleanup/Finishing	NB SR7 Bridge over Churchmans Rd./Wall B	X	X	X	X	X			X	X	X	X	X		
Bridge Deck Construction	SB SR7 Bridge over Churchmans Rd.	X	X	X	X	X			X	X	X	X			
Type B Hotmix Paving	Churchmans Road	X	X	X	X										
Type B Hotmix Paving	SB SR7 Frontage Rd. thru SR4				X										
Signal Head Inst./Adjust. & Loop Detector Inst.	Churchmans Rd. Intersections		X	X	X										
Realigning Traffic to Final Configuration	Churchmans Road		X	X	X										
Safety Barrier	MSE Wall A				X	X									
Light Poles and Wiring	NB SR7, South End Thru Churchmans Rd.								X	X	X				
Pole Base, Conduit, Wire, and Light Pole Inst.	SB SR7, SR4 to North End and other locations										X	X	X		
Guardrail and Impact Attenuator Installation	Churchmans Rd. Median								X	X	X	X	X		
Sign Foundations	GM-9		X												
Sign Installation	All avail. signage required for NB SR7 Opening	X	X												
Opening New Roadway to Traffic	NB SR7 and Ramps B/B-1/C/C-1	X													
PCC Barrier Relocation	Ramps A/D and NB/SB SSR7	X	X												
Remove Hotmix Crossovers	SR7 Med. & SB Roadways @ North & South Ends		X	X	X	X			X	X	X	X	X		
Complete Embankment	SB SR7, North of Churchmans Rd.														
PCC Removal	SB SR7, South End Tie-in			X	X	X									
Complete MSE Wall	MSE Wall A								X	X	X	X	X		

Notes/Legend:

1) All work is weather permitting.
2) All hotmix paving operations are contingent upon plant and crew availability.
3) New Road Opening includes relocating PCC Barrier and pavement striping.
4) Placing Traffic into Final Configuration includes temporary striping placed according to final striping pattern shown on the plans.

Night Work [X] Night Paving 8PM to 6AM [X] Deck Pour [ ] Road Opening [ ]

Rmuir
Project Manager
Greggo & Ferrara, Inc.

FOR THE PERIOD BEGINNING 4/16/01 TO 5/7/01		APRIL														MAY						
		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6
ACTIVITY	LOCATION	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S
Relocating Temp. Barrier	SB I-295/Toll Plaza/Ramps A-D	X													X							
Relocating Temp. Barrier	SB I-295, Stage V(B)	X	X																			
Jersey Barrier	SB I-295 @ Pier 4				X	X	X		X													
Guiderail Removal	SB I-295, Shldr. & Ramp D		X																			
Construct New Service Road (4)	Ramp LN-8	X	X	X	X	X			X	X	X	X	X			X	X	X	X	X		
Replace Toll Lanes	Toll Lanes 4 & 5		X	X	X	X																
Replace Toll Lanes	Toll Lanes 6 & 7															X	X	X	X			
Widening/Reconstruction	SB I-295 Shldr.		X	X	X	X	X		X													
Hotmix Overlay	SB I-295 Lanes 7, 8, & Shldr.			X	X	X	X		X	X	X	X	X	X								
Final Striping, Polyurea	NB I-295 & Ramps E - H								X	X												
Reconstructing Ramps (3)	Ramp D		X	X	X	X	X		X													
Reconstructing Ramps (3)	Ramp B								X	X	X	X	X	X								
Reconstructing Ramps (3)	Ramp A															X	X	X	X	X	X	
Relocating Temp. Barrier	SB I-295, Stage VI(B)															X	X					
PCC Pavement Removal	DE9 Median, Roadway								X	X	X	X	X									
Excavation/GABC	DE9 Median, Roadway										X	X	X			X	X					
Hotmix Paving, Base	DE9 Median, Roadway																	X	X	X		
Backwall Reconstruction	NB & SB DE9 over I-295, Med.	X	X	X	X	X			X	X	X	X	X			X	X	X	X	X		
Demo/Patch Ex. 8' Median	NB & SB DE9 over I-295	X	X	X	X	X			X	X	X	X	X			X	X	X	X	X		

Notes/Legend:

1) All work is weather and/or temperature permitting.
2) Hotmix Paving is dependent upon crew and plant availability.
3) Ramp Reconstruction includes patching PCC pavement, excavation, GABC, u'drain, and hotmix paving. MOT for Ramp Reconstruction includes full closure and detour of traffic during construction.
4) New Service Road Ramp LN-8 construction includes slope stabilization using Gabions and Reno Mattresses.

Night work requiring lane closures [X] Hotmix Paving [X]

Rmuir
Project Manager
Greggo & Ferrara, Inc.

3.6.13 CPM Enhancements

Commercial scheduling software solutions provide users with capabilities far beyond hosting, computing, and maintaining CPM networks. Primavera utilizes a database as a repository of all schedule information. This configuration alone adds significant capabilities. Organizing and reporting can be based on and include any number of schedule parameters. Database functionality enables organizing via grouping, sorting, and filtering of schedule information. Filtering is based on various combinations of selection criteria including dates, float, performance indicators, and many other parameters. Selection operators not only include “equal to”, “not equal to”, “greater than”, “less than”, “within the range”, but also “contains”. The “contains” operator allows selection based on a particular word or phrase in an activity’s description. Activity coding greatly expands the program’s ability to organize information in similar fashion to schedule parameters. Coding is applied to delineate or define an activity’s location, phase or stage; responsibility at various levels; process, operation, or step; trade or craft; or any other criteria necessary to effectively describe and manage the work plan.

CPM enhancements include multiple calendars that can be customized to exclude prescribed non-work periods from the work plan. Standard calendars can be set to prescribed workweeks. For instance, a 5-Day workweek calendar can be set to exclude Saturdays and Sundays as workdays. A 4-Day workweek calendar can be set to exclude Fridays, Saturdays, and Sundays, leaving Monday through Thursdays available to be scheduled as workdays. Holidays can easily be excluded from workdays. Shutdowns or extended periods of inactivity such as those mandated by winter weather conditions can also be programmed as non-work periods. Primavera offers the capability of applying base calendars to individual activities (one base calendar per activity) and resource calendars to individual resources.

Another enhancement provided by Primavera System software is "constraints." In Primavera, a constraint is a mechanism used to override the logic that exists within the network. An artificial constraint is an imposed restriction used to reflect project requirements that cannot be easily built into the logic. Constraints aid in building a schedule that more accurately reflects the real world. They are restrictions placed upon activities, which set limitations on the schedule in response to external conditions including contractual requirements (Hinze 2008). Constraints are also useful in reflecting permit requirements or other conditions in which activity calendar restrictions would not be appropriate. While date constraints are probably the most used type of constraint, float and duration can also be artificially constrained. Date constraints include start-no-earlier-than (SNET), finish-no-earlier-than (FNLT), start-no-later-than (SNLT), finish-no-earlier-than (FNET), Start-On, and Mandatory Starts/Finishes. This type of constraint requires defining a specific date to override the standard CPM algorithms (O'Brien and Plotnick 2010)[50]. Float constraints include zero total float (ZTF) and zero free float (ZFF). The ZTF constraint overrides the algorithms by inserting the calculated LF as the activity's EF resulting in TF = 0. With the ZFF constraint, the LS and LF are inserted in place of the activity's ES and EF (O'Brien and Plotnick 2010). Setting an end date or "Project must finish by" in the Project Overview window is essentially applying an artificial constraint upon the schedule.

[50] O'Brien and Plotnick use the logical operator "not" in place of "no" to form the compound adjectives represented by the acronyms SNET, SNLT, FNET, and FNLT.

Scheduling software such as the Primavera Systems products provide users with the ability to load resources and costs into the schedule. Resource allocation within the schedule not only expands reporting capabilities, but facilitates management's ability to balance or level resources across the project. P6 allows resources to be leveled across the enterprise. Special activity types (Independent and Meeting activity types in P3 and Resource Dependent types in P6) allow the calendars of driving resources to govern in computing boundary dates. Profiles and tables in Primavera display the periodic and cumulative allocation of resources over time (Primavera 2009). Resource leveling can be achieved via smoothing, splitting, stretching, or crunching. Smoothing is performed by delaying activities, which have positive float in order to minimize utilization peaks and valleys. Splitting allows tasks to be split into noncontiguous time periods by suspending and resuming work according to resource availability. Stretching is proportionately increasing the duration of an activity according to a reduction in per time period resource requirements. Crunching involves using more resource units per time period than initially allotted. Costs can be assigned to resources, presumably boosting the schedule's usefulness as a management tool. Tracking and statusing costs at different levels of detail via defined cost accounts can be useful in projecting cash flows and performing Earned Value Analysis.

3.7 Earned Value Management

Earned Value Analysis (EVA) and Earned Schedule Analysis (ESA) are methodologies within Earned Value Management (EVM) intended to analyze and control construction progress[51]. Early development of a system to integrate cost control with time management while considering scope was attempted by the originators and early users of PERT and CPM. However, the Cost/Schedule Control System Criteria (C/SCSC) developed by the Department of Defense in the late 1960s was the first such system to gain acceptance for practical application and is the basis for EVM found in current practice (Stretton 2007)[52]. EVM is a set of methodologies for determining numerical performance indicators. It consists of widely accepted concepts believed effective for monitoring and reporting progress against the project budget and schedule baselines. The analysis occurs as a snapshot in time at a specified Data Date. The planned vs. actual progress is assessed at that point revealing variances in schedule and cost performance. In addition to indicating performance up to the Data Date, EVM methods are is used for forecasting completion date and final cost. EVM can be applied to an individual activity, a work package or summary activity, or project-wide. Contemporary project management views the proliferation of EVM in an organization as a measure of corporate project maturity (Fleming and Koppelman 2006). It is considered to be a function of how effectively an organization combines scope, money, and time in their variance control efforts. ANSI Guidelines address planning, scheduling, budgeting, accounting issues,

[51] While EVM has become somewhat synonymous with EVA, the author believes that EVM is more properly described as consisting of the subset methodologies of EVA and ESA. EVM includes the management framework necessary to implement the methodologies.

[52] C/CSCS was preceded by PERT/Cost imposed upon defense contractors by DOD and NASA. The latter was found to be unduly burdensome and tedious and according to Stretton, almost killed the proliferation of network scheduling as a management tool (Stretton 2007).

reporting, etc. and includes standards for EVM[53]. EVM is perceived as the integration of the performance, cost, and schedule aspects of the work in an expected sequence.

EVM requires a cost-loaded schedule for each task activity. The representative quantity or "units" or similar metric required must be specified for each task. Statusing includes recording accrued cost and the amount of work actually completed. As work is completed, it is considered "earned." EVA refers to the computation of how much work has been completed on the basis of what was budgeted for the work that has actually been performed (Hinze 2008). There are three (3) key EVA values. These include Planned Value (PV), Actual Cost (AC), and Earned Value (EV). PV is baseline budgeted cost also referred to as "Budgeted Cost of Work Scheduled" (BCWS). It is the approved cost estimate planned to be spent on a given activity over a specified period of time. AC is the total cost incurred in performing work on an activity in a given period. It is also denoted as ACWP; the abbreviation for "Actual Cost of Work Performed." EV is the earned value of work actually completed or "Budgeted Cost of Work Performed" (BCWP)[54]. All EVA calculations are derived from these three values.

The EVA values are combined and applied to the schedule up to the Data Date to determine if work is being performed as planned and within budgeted amounts. As previously mentioned, the deviation between the planned and actual performance is referred to as variance. EVA measures the cost and schedule variances differently than other approaches to measuring budget and time performance. The Cost Variance or CV

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[53] ANSI/EIA-748A standard published in May 1998 and reaffirmed in August 2002. The standard defines 32 criteria for full-featured EVM system compliance. A draft of ANSI/EIA-748B, a revision completed in 2007 is available from ANSI.

[54] The author favors the PV, AC, and EV nomenclature over BCWS, ACWP, and BCWP. The former was promulgated by the Project Management Institute (PMI) in 2000 and continues to gain preference in contemporary practice (Turner et al 2010).

= EV – AC and the Schedule Variance or SV = EV – PV. Negative CV indicates that the activity or project is over budget and a negative SV indicates the activity or project is behind schedule. Keep in mind that in the United States, both CV and SV are expressed in dollars. However, variances can also be expressed as percentages. CV% = CV/EV x 100, which gives the percentage variance of the actual costs incurred vs. the budgeted amount for the work performed to the Data Date. SV% = SV/PV x 100, which gives percent variance from the schedule based on budgeted cost values (Hinze 2008).

EVA calculations include those intended to yield efficiency indicators referred to as Cost and Schedule Performance indices. The Cost Performance Index or CPI is the quotient of EV/AC. The Schedule Performance Index or SPI is calculated by EV/PV. Perceived power of EVA includes the ability to forecast future performance based on performance to the Data Date. CPI or SPI < 1 indicates poor performance, while indices ≥ 1 indicates performance at or above the plan. Interpreting the variances and resulting performance indicators in terms of project position, it can be said that a Negative Position is one that is on budget but behind Schedule. A Mixed Position is when the project or component is under budget but behind schedule. A Bad Position is when the project is both over budget and behind schedule. The best scenario of course is a Positive Position in which the project is both under budget and ahead of schedule. One method of depicting project position graphically is by plotting the CPI and SPI on an Earned Value Matrix as shown in Figure 28.

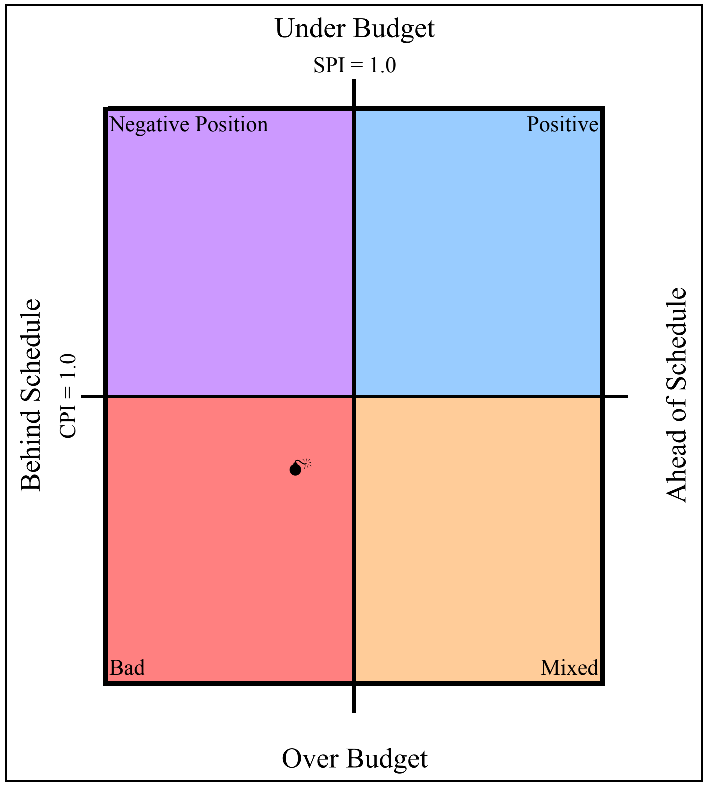

Figure 28 – Earned Value Matrix

As is in the case with the performance indicators, projections are based on the three EVA values. The total PV at the end of the project is referred to as Budget at Completion (BAC). EVM projection values include Estimate to Complete (ETC), Estimate at Completion (EAC), Variance at Completion (VAC), To-Complete Performance Index (TCPI), and Independent Estimate at Completion (IEAC). The ETC is computed by BAC - EV. The EAC is referred to as the manager's projection of total final cost. EAC = AC + (BAC – EV)/CPI and VAC = BAC – EAC. A slightly less precise formula for computing the EAC is BAC/CPI.

The TCPI is a projection of the predicted performance necessary to realize the BAC or EAC. The performance required to achieve the original BAC is computed as: $TCPI_{BAC}$ = (BAC – EV)/(BAC – AC). Computation of the performance index required to hit the adjusted or revised budget final amount: $TCPI_{EAC}$ = (BAC – EV)/(EAC – AC). The Independent estimate, as opposed to what is referred to as the manager's projection (EAC) is computed as IEAC = ∑AC + (BAC - ∑EV)/CPI. The following is a set of EVA calculations for a project with a BAC = \$10,000,000. The EVA values at a particular Data Date are EV = \$800,000, PV = \$1,000,000, and AC = \$1,200,000. Note that all but the $TCPI_{EAC}$ and IEAC can be computed with the information provided.

CV = EV – AC = \$800,000 - \$1,200,000 CV = -\$400,000

CV% = CV/EV x 100 = -\$400,000/\$800,000 x 100 CV% = -50%

CPI = EV/AC = \$800,000/\$1,200,000 CPI = 0.67

SV = EV – PV = \$800,00 - \$1,000,000 SV = -\$200,000

SV% = SV/PV x 100 = -\$200,000/\$1,000,000 x 100 SV% = -20%

SPI = EV/PV = \$800,000/\$1,000,000 SPI = 0.80

ETC = BAC – EV = \$10,000,000 - \$800,000 ETC = \$9,200,000

EAC = AC + (BAC – EV)/CPI = \$1,200,000 + (\$10,000,000 - \$800,000)/0.67

EAC = \$14,931,343 say \$14,950,000 …using the less precise approach

EAC = BAC/CPI = \$10,000,000/0.67 = \$14,925,373 …<1% error

VAC = BAC – EAC = \$10,000,000 - \$14,950,000 VAC = -\$4,950,000

$TCPI_{BAC}$ = (BAC – EV)/(BAC – AC)

= (\$10,000,000 - \$800,000)/(\$10,000,000 - \$1,200,000) $TCPI_{BAC}$ = 1.045

The project in the example is clearly in trouble. The CPI and SPI are plotted on the Earned Value Matrix in Figure 28. Obviously, the project is in a bad position. If the current level of performance is maintained as-is, the project will finish approximately \$4,950,000 over budget. At this early stage of the project (\$1,000,000 PV of a \$10,000,000 job), the performance only needs to be brought up to a CPI of 1.045. In other words, the cost performance going forward only needs to be 4.5% better than planned in order to meet the final budget. Then again, this represents an overall improvement of 24.5%, which is rather significant. The SPI = 0.80 indicates that the project is behind schedule and without corrective action will finish late. Essentially, the project is only achieving 80% of the planning schedule objectives. Although the SPI is a telling performance indicator, the shortcoming of EVA is that it fails to quantify schedule performance in pure terms of time. The EVA output fails to indicate the actual amount of time that the project is behind. Nor is there a direct forecast of the final project duration. Implicit in EVA is the ability to forecast the final duration as the quotient of the original duration/SPI. However, the more recently developed ESA methodology translates EVA dollar amounts into units of time.

3.7.1 Earned Schedule

Earned Schedule is considered an extension of EVA intended to yield practical schedule information stated in terms of time, not dollars (Anbari 2003). As stated, the author views ESA as a set of techniques within EVM or part of an EVMS. ESA generates time performance indicators that are more useful in practical time management than EVA metrics. Translation of the EVM input values to units of time can be accomplished graphically, but yields more definitive results when computed algebraically. The Earned Schedule (ES) metric is the duration from t = 0 to the point in time where PV equals EV, when the latter is observed from the Data Date (referred to as the Status Date in the figure) as shown in Figure 29[55]. Computation of time variances (TV or SV(t)), schedule performance index in terms of time (TPI or SPI(t)), and the independent estimate of time at completion (IEAC(t)) all require direct time inputs. Actual Time (AT) is required to compute the variance and performance indices. AT is the number of planning units (day, weeks, or months) from t = 0 to the Data Date. TV = ES – AT. The overall project duration referred to as planned duration (PD) or Time at Completion (TAC)[56] is needed to forecast the IEAC(t). PV is a component of the time-based ESA values. The plot of the cumulative PV over the course of the project is referred to as the Performance Measurement Baseline (PMB). The PMB usually forms a somewhat rough lazy "S", which is typical of production and expense curves (Halpin 2006)[57]. Another example of a PMB and other ESA attributes are shown in Figure 30.

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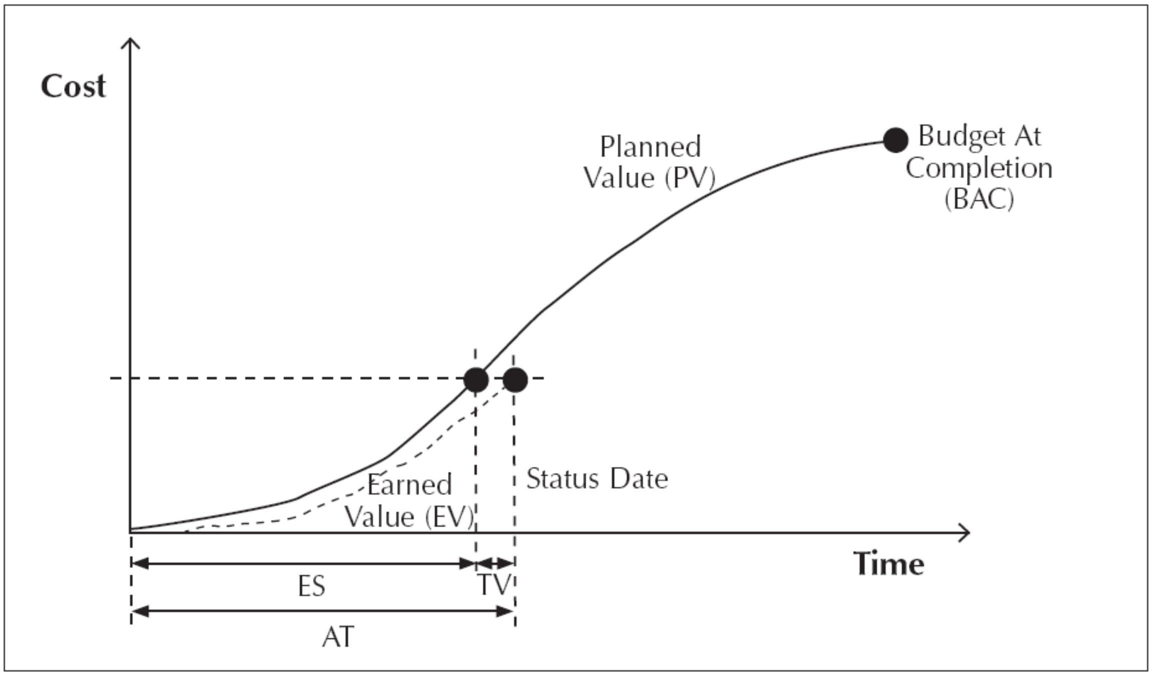
[55]Regrettably, EVM uses ES as an abbreviation for Earned Schedule, while in CPM ES is widely recognized as an activity's Early Start.

[56] The author prefers the nomenclature PD over TAC so as not to confuse the latter with the term "takt time". The author further suggests using IETAC (Independent Estimate of Time at Completion) rather than IEAC(t) for greater clarity and distinction and to elevate the status of ESA

[57] Production curves are also referred to as velocity diagrams and can also be plots of time-units or time-distance in addition to time-$ (Halpin 2006)



Source: Adapted from Anbari, 2003; Lipke et al., 2009; Lipke, 2009; Turner et al., 2010.

Figure 29 – Earned Schedule Analysis

The ES can be determined graphically by extending a horizontal line from the EV at the Data Date to the intersection with the PMB. A vertical leader line is then drawn from the end of the horizontal at its juncture with the PMB down to the timescale. The distance between the EV and PV is readily observable as time and is in fact the TV or SV(t). If the horizontal line extends left from the Data Date toward t = 0, the TV is considered to be negative and the activity, work package, or project is behind schedule. Another way of expressing this is to say that if AT > ES, then TV is

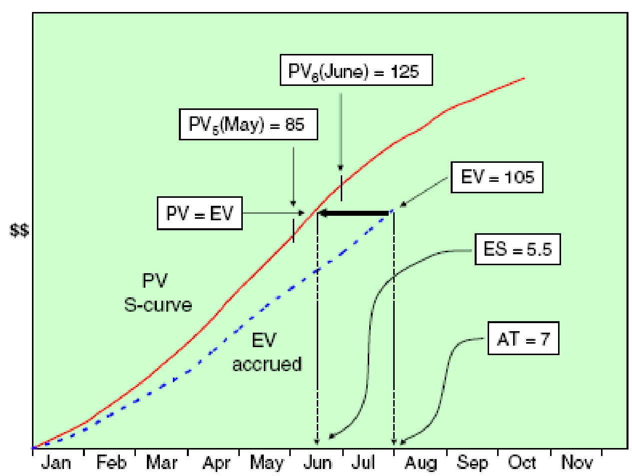


Figure 30 – Earned Schedule Analysis Example

negative since TV = ES – AT. Conversely, if the horizontal line extends from the Data Date to the right toward t = f, the variance is positive and is ahead of schedule. In this positive case, AT is less than ES. The graphical method can produce a reasonably close approximation of TV and ES, provided that the PMB and EV are plotted accurately and that the horizontal line and vertical leader are drawn carefully. The ES is more precisely determined through algebraic calculation.

The two variable components of ES are denoted as *C* and *I*; the latter of which requires linear interpolation for its determination (Lipke et al 2009). The component *C* represents the number of whole time increments from t = 0 to the point where the horizontal line representing the TV intersects the PMB[58]. This point is designated as PV_C. The time increments represent reporting periods, which typically coincide with monthly schedule updates. Component *I* represents the incremental portion of PMB beyond PV_C. PV_{C+1} represents the next reporting period after PV_C. *I* is an interpolated value computed as $I = (EV - PV_C)/(PV_{C+1} - PV_C)$. ES is computed as ES = *C* + *I*. While *I* is an estimate and subject to some error, it is rather minor since the interpolation is performed over a single reporting period. As the project progresses and *C* becomes larger (more reporting periods between t = 0 and PV_C, any error introduced by *I* diminishes in significance. Incidentally, TV can be approximated by SV/PV_{RATE}, where PV_{RATE} = BAC/PD. The opportunity for error is much greater with this approach since the PMB is not a straight line, but is curvilinear with rates that vary over time (recall the lazy "S"). Once again, the closer the Data Date to t = f, the smaller the error. Regardless, time indicators are calculated more accurately by ES = *C* + *I*.

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[58]Identifying the location of this incremental point is facilitated by first plotting the PMB, EV, TV, and ES as one would when solving graphically.

Continuing with the previous EVA example, the PD = 425 CDs (14 months) beginning 01March. The EVM metrics are measured and reported on a monthly basis to coincide with the regular schedule updates. For this example, the EVM metrics are measured and reported along with Schedule Update No. 2 after the first two months. Therefore, the Data Date = 01May and AT = 2. Plotting the PMB and the EV at the Data Date reveals that the PV equal to the EV occurs in April. PV_C occurs at the end of March (Data Date = April 1st), therefore, $C = 1$. PV_C = \$400,000 and PV_{C+1} = \$1,000,000. The EVS calculations are as follows:

ES = $C + I$

$I = (EV - PV_C)/(PV_{C+1} - PV_C)$ $\quad$ $I = (800{,}000 – 400{,}000)/(1{,}000{,}000 – 400{,}000)$

$I = 0.67$

ES = 1 + 0.67 $\quad$ ES = 1.67

TV = ES – AT $\quad$ TV = 1.67 – 2.00 $\quad$ TV = –0.33 months or 10 CDs behind schedule

(365/12 x 0.33 = 10)

The estimated final duration is projected by IEAC(t) = PD/TPI. To reiterate, IEAC(t) is the independent estimate of time at completion; PD is the overall Planned Duration; and TPI is the schedule performance index reported in units of time. The TPI is simply calculated as TPI = ES/AT.

IEAC(t) = PD/TPI

TPI = ES/AT   TPI = 1.67/2.00   TPI = 0.835

IEAC(t) = 425/0.835   IEAC(t) = 509 CDs

TV_{PD} = PD – IEAC(t) TV_{PD} = 425 – 509 TV_{PD} = –84 CDs

Research confirms that ESA calculations, specifically IEAC(t) are more reliable than the EVA-based schedule forecasting methods (Lipke et al 2009). Furthermore, ESA-derived metrics are relevant beyond the PD when the original time allotment is exceeded. EVA-based metrics are meaningless beyond the PD.

Test of EVA methods and other approximations

TV ≈ SV/PVRATE

PV_{RATE} = BAC/PD PV_{RATE} = \$10,000,000/425 CDs PV_{RATE} = \$23,529/CD

or \$714,286/month

TV ≈ –200,000/714,286   TV ≈ –0.28

e_{TV} = –0.33 – (–0.28) e_{TV} = –0.05 e_{TV}% = (–0.05/–0.33) x 100 e_{TV}% = 15% low

Final duration (FD) roughly approximated from EVA

FD = PD/SPI   FD = 425/0.80   FD = 532

Error between IEAC(t) and FD

e = IEAC(t) – FD e = 509 – 532 e = –23

e% = e/IEAC(t) x 100 e% = –23/532 x 100 e% = –4.3%

3.8 Conclusion

The information presented in this chapter is intended to inform the reader of Contemporary Approaches to Construction Planning & Scheduling. The emphasis is on delivery of bridge and highway infrastructure, but not to the exclusion of other industry divisions and sectors. The information presented is not exhaustive but is intended to impart a basic understanding of the subject in order to maximize learning and appreciation of the topics that follow.

CHAPTER 4: HIGHWAY PROJECT DELIVERY

4.1. Historical Development of the U.S. Highway Industry

Public roads and bridges trace their roots to the colonial era[59]. In fact, Native Americans originally traveled some routes such as the Natchez Trace[60]. Early rural roads evolved from horse paths extending between settlements and/or waterways. Colonial authorities established mail service between cities and these couriers and stage-wagons carrying passengers depended on these primitive roads. Construction and maintenance of these roads was the responsibility of the local authorities. Outside of the cities, this responsibility fell to the towns in New England and the counties in the rest of the rest of the colonies.

In the New England towns, the duties of maintaining the highways, private ways, causeways, and bridges were executed by an elected surveyor of highways. These officials were authorized to remove obstructions from the roadways and to dig for suitable materials in land that was neither planted nor enclosed. The surveyor of highways also supervised the labor force required to work on these roads. The labor force was comprised of all persons over the age of 16 on appointed days after official public notice of the work. Road work in Virginia was directed by the county court. The county court would then contract to have the required work completed or would have it performed at no charge by the "tithable males" directed by the precinct surveyors or

[59] Interestingly, the States included in the Highway Project Performance (HPP) Study within this thesis were all original colonies. The sole exception is West Virginia which of course was originally part of the Commonwealth of Virginia.

[60] Much of the information presented in this section was synthesized from the book *America's Highways 1776-1976* published by the U.S. Department of Transportation, Federal Highway Administration, 1976.

foremen. Local residents over the age of 16, whether free, slave, or indentured were considered tithable. Not surprisingly, owners of two or more tithable persons could send those men rather than perform the work themselves.

Basically, all of the colonies used similar approaches for maintaining their roads. The colonial governments authorized local authorities to mandate that residents either performed the work or paid an equivalent amount in cash. This was referred to as "statute labor" and served as a primary resource even into the early 1900s in some states. After the War of Independence, the burden of maintaining some of these roads became too great for the local authorities who began to seek assistance from the State. The States in turn sought the necessary resources, particularly funding from private sources. Beginning in 1785, individual States chartered private turnpike companies to build and maintain certain roads. The charters authorized turnpike companies to not only build roads on public land, but also to charge tolls for their use.

These turnpike charters resemble the public private partnership concessions emerging today as alternative procurement strategy for cash-strapped States. The charters specified the road limits and set minimum engineering standards. Typically, the turnpike company was authorized by the State to collect tolls at rates established by the Legislature. They were also granted the power of eminent domain to procure right-of-way and road building materials. However, some of these turnpikes involved state subsidies or at least the State acquiring stock shares in these private companies. The spread of tolls roads occurred simultaneously with an expansion of toll canals. The two modes co-existed without much direct competition. Toll roads were generally well built for the time. Toll road construction improved with greater infusion of engineering and better administration. The roads were built by contractors or at the very least supervised by professional road builders, which was a significant improvement over statute labor.

Financing roads in the new States north and west of the Ohio River was different then that for the original colonial states and other early states. The undeveloped land was owned by the United States. Sale of this land was a source of revenue for the young country. A portion of the proceeds from the sale of land was used to build roads in these new states, thus providing improvement that enhanced the value of the land which the states themselves could not afford to do. Generally, 5% of the net proceeds were under the control of the new state's legislature and the Federal government to build roads to and through new states used 2% of the proceeds. This eventually applied to all States except the original thirteen, Maine, Vermont, Kentucky, Tennessee, West Virginia, and Texas.

The Secretary of the Treasury Albert Gallatin who also performed the first inventory of national transportation resources in 1807 conceived the basic concept in 1801. Gallatin was ahead of his time in recognizing the value of transportation to a nation's prosperity. He recognized that in a developing country like the U.S., commerce alone could not support construction of an expensive road network, but must rely on the Federal government to finance and execute the work. He proposed utilizing surplus government funds to finance a 10-year, $20 million national road and canal program. He proposed that the program would stimulate internal development, substantially increase the value of the unsold Federal lands, bolster the national defense, and generally unite an ever-growing young country. He stated "no other single operation, within the power of the Government, can more effectively tend to strengthen and perpetuate the Union which secures external independence, domestic peace, and internal liberty." In spite of its obvious benefits and the fact that there were sufficient funds to cover the cost, Gallatin's plan was rejected.

In 1806, President Jefferson approved legislation that required that he appoint three commissioners to plan and construct a road from "the head of navigation on the Potomac River at Cumberland, Maryland to a point on the Ohio River." President Jefferson first had to secure the approval from the legislatures of the three states through which the proposed road would traverse. These included Maryland, Virginia, and Pennsylvania. All concurred, but Pennsylvania's approval was contingent upon the proposed road passing through the towns of Uniontown and Washington. The planning phase, which was essentially route selection, took 4 years and construction consumed 8 years. The road ran from Cumberland to Wheeling, Virginia and thus, the Cumberland Road also called the "National Road" was opened to traffic in 1813. The National Road was very heavily traveled and steadily deteriorated, a situation in which the commissioners were unable to redress. In response, Congress authorized collection of tolls in order to provide adequate funding to maintain the Cumberland Road. However, President Monroe vetoed the act on the basis that it was an unwarranted extension of Federal power. Monroe believed that it was acceptable for the Federal Government to finance public improvements, but unconstitutional to assume jurisdiction over State land upon which the improvements were made.

Monroe's decision had quite an impact at that time and it remains the Federal position on highway grants to the States even today. Maryland, Virginia, Pennsylvania, and Ohio legislatures agreed to take possession and maintain their respective sections of the National Road after the Federal Government restored the condition of the road and erected tollgates to enable the States to collect the user fees. The significance here is that these sections financed by Federal dollars essentially became the first state highways. Plans were in place to extend the National Road west through St. Louis to Jefferson City, Missouri. However, funding became a problem and construction was terminated at Vandalia, Illinois in 1839. The larger issue was the belief that roads were being supplanted by railroads for long-distance travel.

Other roads considered by Congress around the same time included The Maysville Turnpike in Kentucky. However, President Jackson vetoed this associated bill on the grounds that it was not connecting to any existing system and was solely located within the bounds of Kentucky, and therefore was strictly of local importance, not national. Jackson's veto effectively curtailed further Federal funding for local improvements. The Maysville Turnpike was eventually completed through State and private funding. Ironically, the Federal Government claimed that it could freely use the road to carry mail since it had long been a mail route. The courts found in favor of the Turnpike Company, requiring the Federal Government to pay the same tolls as the public for use of the Maysville Turnpike. Through this period, the Federal Government supported the construction of various roads in the public lands and other roads deemed to have military significance. However, railroads dominated the latter half of the nineteenth century. The period between 1850 and 1900 are sometime referred to as the "dark age of the rural road."

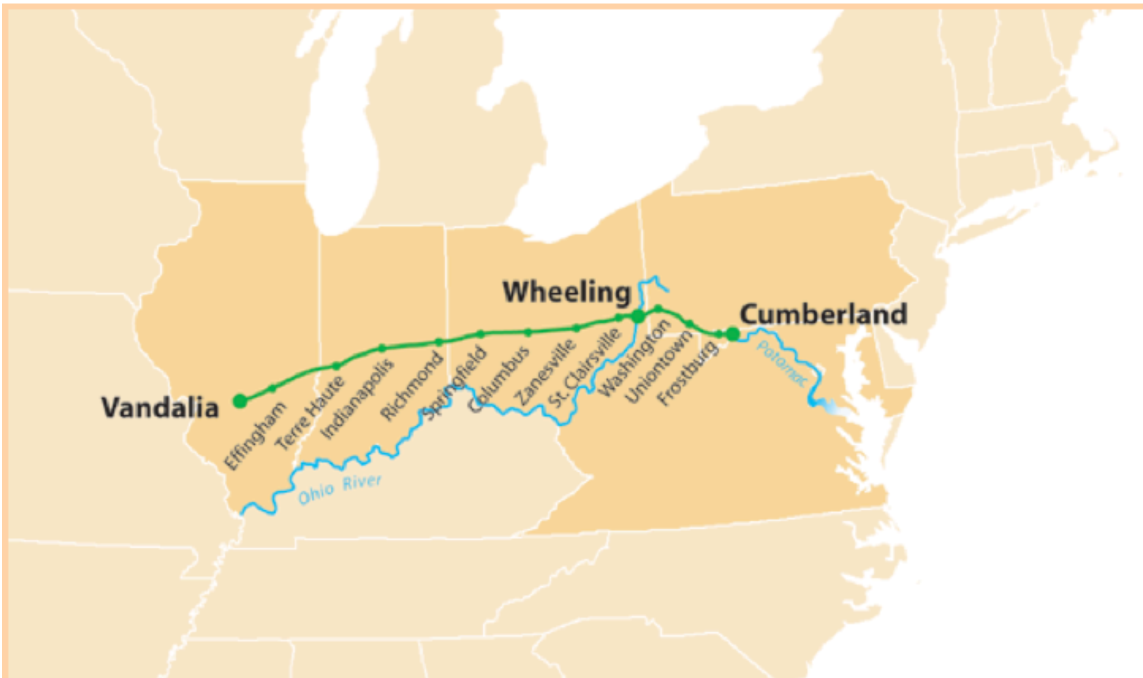


Figure 31 - Map showing the route of the National Road at its greatest completion in 1839, with historical state boundaries
Taken from *America's Highways 1776-1976*

Financing of rural roads remained sparse into the early 1900s. Primary sources of funding included property taxes, poll taxes, and statute labor. Bond issues were typically not an option. Some states did not permit counties and townships to issue bonds for road construction. Such issues were generally reserved for projects such as large bridges. Rural roads, especially those developed in the public lands were often only ditched and graded. Conversely, urban roads and streets were a different story. City dwellers and those in the ring suburbs generally enjoyed good transportation. Main streets were built heavily with granite blocks or hard brick pavers. Minor streets were constructed of macadam or gravel and eventually paved over with asphalt surfacing. Streets in Philadelphia and New York were first paved with asphalt in 1871. Many other cities followed suit by 1900.

Funding for urban streets was much more easily acquired then for rural facilities. Concentrated populations, trade, and industry provided a substantial tax base. Property taxes were often augmented by special assessments for various public works projects including streets and bridges. All improvements were directed by engineers, executed by professional road builders, and paid for by tax dollars. The excellent transportation within and adjacent to cities enhanced the quality of urban life while poor transportation systems detracted from the quality of urban life.

The extreme inequality between urban and rural standards was obvious. Most urbanites had little care about poor rural conditions. However, some high-minded city leaders recognized that the poor rural transportation systems affected not only the farmers, but ultimately the city dwellers as well. North Carolina was the first state to allow a county to levy a road tax on all property in the county. Mecklenburg County in North Carolina sought to levy such a tax and after much wrangling, did so in 1885. This policy resulted in the County having the best roads by far in North Carolina to the great benefit of the entire county. This included the City of Charlotte as well as the outlying countryside. The Mecklenburg model would eventually serve as a model for others and marked the beginning of the "Good Roads Movement."

Iowa City, Iowa hosted the first State road convention in 1883. The event was precipitated by the need to address the very poor condition of the rural roads in the State.

Recommendations coming out of the Convention included payment of road taxes in cash rather than labor, visa vie statute labor and instead having competent contractors build the roadways. Other recommendations included consolidation of road districts and permitting county boards to levy a property tax to create a road fund. The Iowa Legislature subsequently adopted the recommendations in 1884. While the events in North Carolina and Iowa began the Good Roads Movement, an unlikely group really provided the impetus for change. That group was the organized bicyclists.

Bicycles gained popularity as practical vehicles for personal transportation starting in the mid-1880s. Cycling became a national craze almost instantly. Cyclists or "wheelmen" as they were called sought to expand their riding range beyond the city into the countryside. Wheelmen held cross-country rallies, road races, and expeditions through rural environs. The country roads however proved to be quite inhospitable and the wheelmen became staunch advocates of good roads. Several local cycling organizations known as "wheel clubs" merged into a national organization known as the League of American Wheelmen in 1880. The group realized that the quality of the roads was critical to their sport and launched in intense public relations and lobbying campaign to promote road improvement. Eventually, a magazine titled *Good Roads* was published and distributed well beyond the cycling community. Coincidently, a gentleman edited the magazine by the name of I.B. Potter, who happened to be a civil engineer and lawyer from New York. The magazine was successful in favorably shaping public opinion regarding the value of good roads and the necessity to support their improvement through tax revenues.

The next phase of the Good Roads Movement included the formation of the "Good Roads Association" in Missouri in 1891 with comparable organizations popping up in other States. The first national road conference was convened in July 1894 in Asbury Park, New Jersey that included representatives from 11 states. The conference was sponsored by New Jersey Road Improvement Association and endorsed by the National League for Good Roads, the New-York State League, and the Maryland Road League, and the U.S. Department of Agriculture's Office of Road Inquiry (a forerunner to the modern FHWA). The primary outcome included the push for States to adopt effective legislation to implement good roads programs. It was proposed that State legislatures establish temporary highway commissions to probe and recommend the appropriate legislation. New Jersey was one of the first States to actively embark on that journey. These efforts were initially championed by the New Jersey Road Improvement Association.

Road Improvement in New-Jersey.

ORANGE, N. J., Dec. 19.—James S. Holmes, Jr., of this city, ex-Chief Consul of the New-Jersey Division of the League of American Wheelmen; County Engineer James Owen, Edward Boroughs, State Road Commissioner for New-Jersey; E. G. Harrison, Secretary of the New-Jersey State Road Improvement Association, and Gen. Roy Stone, the head of the Road Improvement Department at Washington, held a conference in the office of the County Engineer in Newark yesterday afternoon, and considered the question of road improvement in this and other States, and the enactment of appropriate legislation for the building of stone roads.

The proposed new law for passage in this State, which is to combine all the desirable provisions of existing laws bearing on roads, with many improvements on them, was discussed at length. The meeting was entirely informal, and while many plans for road improvement in general were proposed and discussed in detail, no decisive or final mode of action was formulated.

The New York Times
Published: December 20, 1894

Figure 32 - New York Times Newspaper Clipping

Entering the 1890s, all of New Jersey's public roads beyond the cities fell under the local township jurisdiction. The townships bore the expense of building and maintaining these roads. While much of the traffic on these roads was of local origin, some was actually from locations beyond the local township and even outside of the county. In fact, the New Jersey Road Improvement Association demonstrated that the traffic on main roads was really inter-county in nature. The Association contended that it would be much more equitable if the State and counties bear part of the cost of construction and maintenance of these roads. The Association along with the League of American Wheelmen promoted this idea and supported a State-aid bill in the Legislature. The bill was enacted into law on April 14, 1891. The State-aid act was significant in that it articulated the notion that road improvement for the general good was a duty of the State, county, and property owners along the highway. The law split the cost of construction or other improvements three ways. Property owners along the road were assessed one-tenth of the cost, the State covered one-third, and the county was responsible for the balance (57%). Under the new law, the individual counties were responsible for conceiving, planning, and supervising the improvements. The State reserved the right to approve the projects and to accept or reject contracts. The administration of the State-aid law initially fell to the State Board of Agriculture. This role was taken over by the Commissioner of Public Roads in 1894, making New Jersey the second to establish a State highway organization. Massachusetts was the first State to do so when it established the Massachusetts Highway Commission in 1893.

The Massachusetts Commission consisted of three commissioners appointed by the governor. The Commission was responsible for assisting local governments with road design, construction, mapping and administration. In 1894, the Massachusetts Highway Commission was assigned to cover all costs of the selected road improvements, which would in turn bill the counties for 25% of the costs. Simultaneously, the Massachusetts Legislature launched the Commonwealth Highway Plan, which was more robust than the New Jersey State-aid act. It was more deliberate in focusing spending on the most critical mileage and assuring interconnection of these important roads into a common network. The New Jersey Commissioner of Public Roads was initially less effective than the Massachusetts Highway Commission. While project initiation remained the responsibility of the local authorities in Massachusetts, the Highway Commission had the same rights as the New Jersey Commissioner to approve or reject projects. However, the Massachusetts Commission performed surveys, prepared plans, awarded the construction contracts, and inspected the work. This was a much higher level of control than was applied in the New Jersey model. Massachusetts quickly established statewide standards for highways including the road building materials. The Commission was also responsible for the maintenance of these State roads and could recover a portion of the associated costs from the local governments. Clearly, the Massachusetts Highway Commission served as a model for future State highway agencies. Many other States followed New Jersey and Massachusetts in applying the State-aid principle to some degree. The Legislature in New York gave the State Highway Commission direct or indirect supervision over every public highway in the State.

The Delaware General Assembly passed a Stat-aid law in 1903, which provided for joint state-county funding of new road construction. This act could have launched Delaware’s highway department, except that it was repealed as a result of public disfavor in 1905. The launching of Delaware Highway Department with centralize road construction was delayed until 1917. Delaware's General Assembly passed the Highway

Act of 1917 in response to the 1916 Federal Highway Act, which provided financial assistance for highway construction only to those states with an organized highway department in place (DelDOT http://www.deldot.gov retrieved 9/9/11). By 1917, all of the States had enacted to form of State-aid law with the accompanying administrative organization in response to the Federal Aid Road Act of 1916.

H.R. 7617 was introduced by Rep. Dorsey W. Shackleford of Missouri, and subsequently amended by Sen. John H. Bankhead of Alabama to conform to model legislation crated by the American Association of State Highway Officials (AASHO). Federal Aid Road Act of 1916 was signed by Woodrow Wilson who himself was an early champion of highways. The Act provided Federal funding for rural post roads with the stipulation that there be free access to the public. Funding was apportioned to the individual states based on apportionment factors that included one-third for the state's geographic area, one-third according to the state's population, and one-third according to the existing post road network. This Act, and one similar to it in 1912 were driven by the need to provide adequate postal roads between towns and cities through rural communities. Federal aid was available to all states whose legislature had assented to the provisions of the Act and adopted their own State-aid laws. There was also a requirement for the states to create official highway departments; Congress made allowances with gave the states some leeway in that regard. The U.S. Secretary of Agriculture administered the provisions of the Act, which provided 50% coverage of the actual cost of highway projects including the cost of bridges and culverts. The upset limit was $10,000 per mile. The Act did not provide payment for right-of-way acquisition or preliminary survey and plan preparation. The states were required to submit project plans, surveys, specifications and estimates to the Secretary of Agriculture with their request for aid.

The Federal-Aid Road Act of 1916 is significant for many reasons. For one, it was the first Federal highway funding law and serves as the foundation of the system that remains in place even to the present. Since that time, Federal funding of state highway projects has become a natural part of the process. The administration of the provisions of the Act required expansion of the Office of Public Roads and Rural Engineering (OPRRE). OPRRE became more skilled in engineering and administration, which was matched by their counterparts across the various state highway departments. The OPRRE decentralized into 10 regional districts, with each one headed by an experienced highway engineer. The physical impact of the Act was also quite significant. The Act was vital in extending and improving the Nation's road system. The improved road system enhanced the farmers' ability to take their goods to market. It significantly bolstered rural postal service and greatly helped usher in the age of the automobile. Several others that expanded and refined the involvement of the Federal Government in support of the Nation's highways followed the Federal-Aid Road Act of 1916. These included the Federal-Aid Highway Acts of 1921, 1934, 1938, 1940, 1944, 1948, 1950, 1952, 1954, 1956, 1958, 1959, 1961, 1962, 1966, 1968, 1970, 1973, 1976, 1981 and all of the Highway Trust Fund (ISTEA, TEA-21, and SAFETEA-LU) legislation since then.

Supporters of the Goods Road Movement actually began pressuring Congress for some type of Federal aid for local roads in the early 1890s. The Agricultural Appropriation Act of 1893 set aside $10,000 for the Secretary of Agriculture to investigate the highway and the associated management systems throughout the Nation. In response, Secretary J. Sterling Morton established the Office of Road Inquiry (ORI) under auspices of the Department of Agriculture to gather and disseminate information regarding the current state and best practices regarding the Nation's highways. The legendary civil engineer, General Roy Stone, headed the Office. General Stone's accomplishments included collection and dissemination through printed bulletins in a very short period of time. He also produced a map of the Nation's macadamized and gravel roads. He also employed statistics to compare the cost of roads against the benefits provided. He also proposed and implemented the Object Lesson Road Program copied from Massachusetts intended to instruct road builders, educate the public, and demonstrate the positive economic impact on farms. General Stone's tenure had a considerable impact upon the proliferation and enhancement of highways across the Nation. During that time, he and his deputy were credited with 20 published bulletins and 30 circulars. He also made several presentations at good roads conventions, before state legislatures and to farmer's road institutes.

The ORI was renamed Office of Public Road Inquiries (OPRI) in 1899. A major accomplishment of the OPRI in 1904 was an inventory of all roads outside of cities in the U.S. The OPRI merged with two other small organizations to become the Office of Public Roads (OPR). OPR became a permanent division of the U.S. Department of Agriculture with a proactive role in developing the Nation's highway system. OPR predecessors were viewed as temporary organizations relegated to merely collecting and disseminating information. The name was changed to the Office of Public Roads and Rural Engineering (OPRRE) in 1915. In 1918, the OPRRE was elevated to bureau status within the Department of Agriculture, becoming the Bureau of Public Roads (BPR). The BPR became the Public Roads Administration (PRA) through a governmental reorganization in 1939. The name reverted to the Bureau of Public Roads under the U.S. Department of Commerce in 1949. It remained the BPR until 1967.

The Department of Transportation Act of 1966 created the United States Department of Transportation (USDOT) as a federal Cabinet department of the U.S. government. It BPR with other agencies involved with aviation, railroads, motor freight, and maritime. The USDOT began operations in 1967, at which time the BPR became known as it is today; the Federal Highway Administration (FHWA)[61]. The FHWA and other agencies (FAA, The USDOT is headed by the U.S. Secretary of Transportation, currently Ray LaHood. The current Deputy Secretary of Transportation is John Porcari. The FHWA is currently lead by Administrator Victor Mendez, Deputy Administrator Greg Nadeau, and Executive Director Jeffrey F. Paniati, P.E.

The FHWA's function is to oversee federal funds from the Federal-aid Highway Program used for constructing and maintaining the National Highway System, which consists of Interstate Highways, U.S. Routes and most State Routes. The funding is mostly derived from the federal fuel tax and generally goes to State departments of transportation[62]. FHWA oversees projects using these funds to ensure conformance to federal requirements for eligibility, contract administration, and design and construction

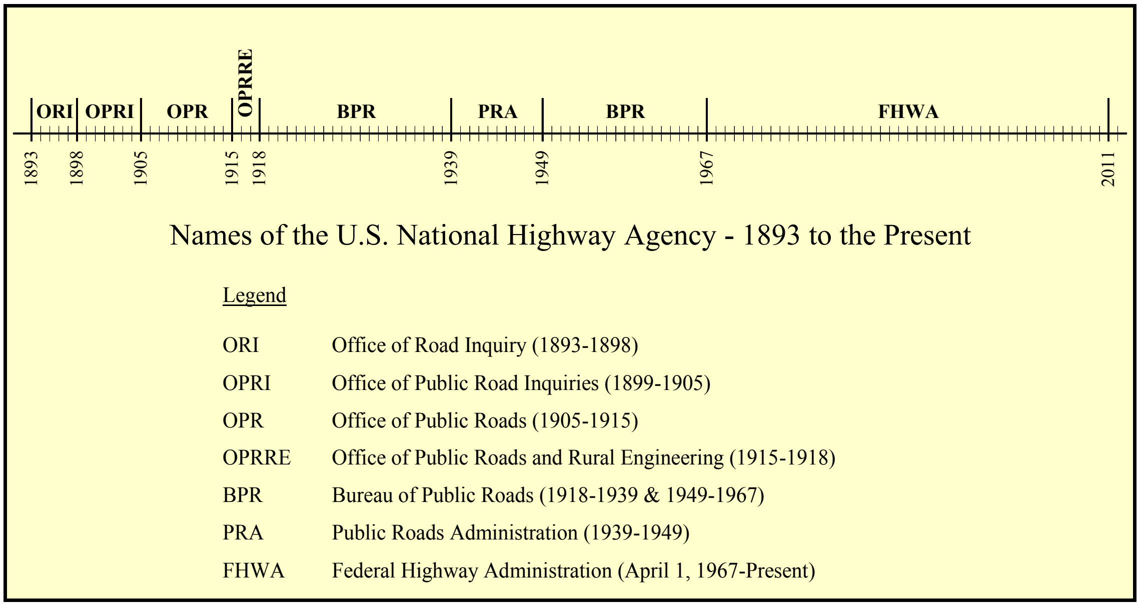
[61] The FHWA and others (Federal Aviation Administration (FAA), Federal Motor Carrier Safety, Administration (FMCSA), Federal Railroad Administration (FRA), Federal Transit Administration (FTA) Maritime Administration (MARAD) are referred to as "child agencies" within the USDOT.
[62] Current Federal fuel tax as of September 2011 is 18.4¢ on gasoline and 24.4¢ on diesel.

standards. An important relatively recent requirement is that the State DOTS must incorporate a formal project delivery process to obtain approval and access to Federal funding. This is no small point and has high relevance within this thesis. The FHWA does not entirely dictate processes, but requires that State DOTs develop and adhere to their own standards and formal framework.

FHWA also provides highway design and construction services for various federal land-management agencies, such as the Forest Service and the National Park Service under the Federal Lands Highway Program.

The FHWA performs research in the areas of automobile safety, congestion, highway materials and construction methods, often in conjunction with the Transportation Research Board (TRB) and American Association of State Highway and Transportation Officials (AASHTO) through National Cooperative Highway Research Program (NCRHP). The FHWA also publishes the Manual on Uniform Traffic Control Devices (MUTCD); a resource that serves as the model document for most highway agencies in the U.S. The MUTCD standardizes characteristics such as the size, color and height of temporary and permanent traffic signs.

Figure 33 - Timeline of the U.S. National Highway Agency



4.2. Contemporary Highway Agency Operations

Contemporary highway agencies are those public entities that develop, deliver, operate and maintain public roads. All states in the U.S. operate a state highway agency, as do the District of Columbia and Puerto Rico. While many states do have county road departments, that role is largely fulfilled at the state level. Many large cities such as New York and Philadelphia operate their own highway agencies with varying degrees of interaction with the State DOTs. Quasi-public agencies exist under bi-state or multi-state agreements to operate bridge or tunnel crossings, shipping ports, and airports.

All of the State agencies who participated in the HPP Study are included in the discussion that follows. Although the Delaware River and Bay Authority (DRBA) and the City of Philadelphia Department of Streets did participate in the HPP Study, those organizations are not included in the discussion. The number of projects delivered annually by these two agencies is miniscule in comparison to the state agencies. Their role in providing, operating, and maintaining valuable infrastructure is nonetheless immense[63]

4.2.1. PennDOT

The Pennsylvania Department of Transportation (PennDOT) is the state government agency responsible for all transportation infrastructure owned by the Commonwealth of Pennsylvania. Although they currently follow the Department's policies and procedures the Pennsylvania Turnpike Commission (PTC) is not part of PennDOT. The Department's Chief Executive Officer (CEO) is the Pennsylvania Secretary of Transportation, presently Barry Schoch. PennDOT's inventory includes over 41,000 miles of state roads and highways, and approximately 25,000 bridges. PennDOT also supervises or supports other modes of transportation including aviation, rail traffic, mass transit, intrastate highway shipping traffic, motor vehicle safety & licensing, and driver licensing. The Department also supports the Ports of Philadelphia, Pittsburgh, and Erie. PennDOT's current annual budget is approximately $3.8 billion, supported by both federal and state motor vehicle fuels tax. PennDOT employs approximately 11,000 people. PennDOT's statewide headquarters is located in the Keystone Building in Harrisburg.

[63] For instance, the DRBA owns and operates the twin spans of the Delaware Memorial Bridge which is a vital link in the U.S. Northeast Corridor

PennDOT was formed in 1970 from the Department of Highways and absorbed several non-highway transportation functions being performed the Departments of Commerce, Revenue, Community Affairs, Forests and Waters, Military Affairs and other state agencies. In 1916, the Federal Government established grants to the states for highway construction. These Federal grants continue today and significantly affect and shape the Department's annual budget. Some of the oldest roads and bridges in the U.S. can be found in Pennsylvania. In 1931, the Commonwealth took over responsibility and control of 20,156 miles of rural roads and embarked upon a massive program of paving rural highways, referred to as the "get the farmer out of the mud" program. The Commonwealth also provides funding to local communities for road maintenance totaling approximately $170 million annually.

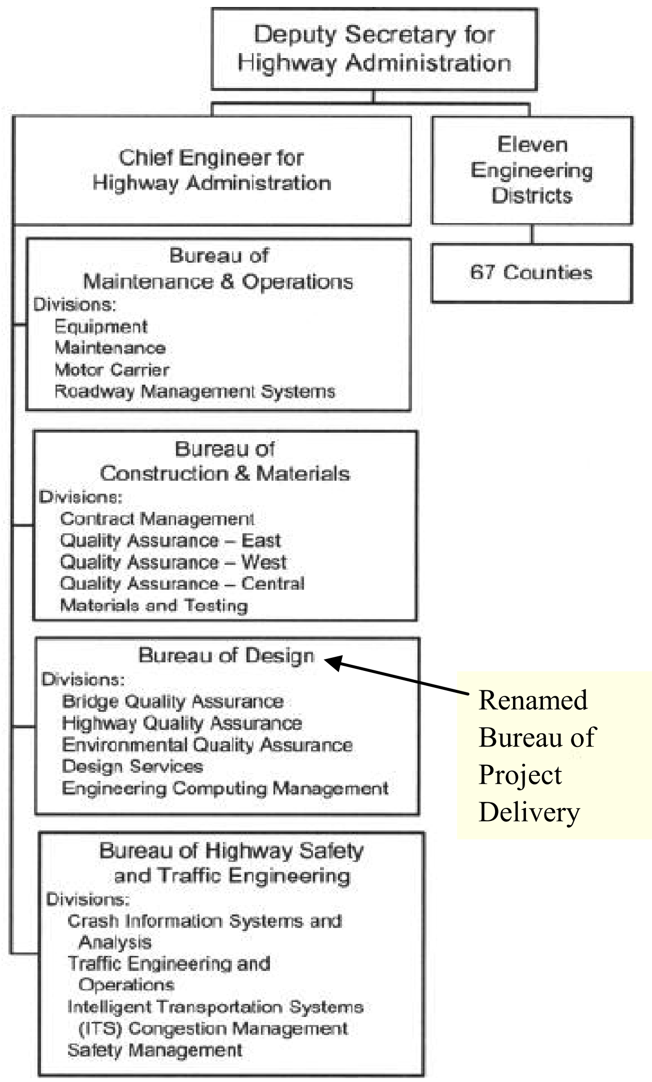


Figure 34 – Portion of PennDOT Organization Chart displaying Highway Administration only
Adapted from http://www.dot.state.pa.us/ retrieved 9/8/11

PennDOT is organized as a functional organization divided into six groups. These include Administration, Planning, Local & Area Transportation, Safety Administration, Aviation, and Highway Administration[64]. A Deputy Secretary heads each of these functional units. Scott Christie, PE, currently heads highway Administration. The Chief Engineer for Highway Administration reports to the Deputy Secretary. The Chief Engineer is responsible for operations of the four Central Office Bureaus; the Bureau of Project Delivery (formerly Bureau of Design), Maintenance and Operations, Construction and Materials, and Highway Safety and Traffic Engineering. "The Chief Engineer establishes, evaluates and implements management systems to improve performance and make informed, cost effective decisions regarding the delivery, operations, maintenance and preservation of PennDOT's transportation system as well as monitoring state and federal policy making laws and regulations and analyze the impact on the Department. The Chief Engineer also maintains liaison with the Department of Environmental Resources, the Department of Labor and Industry, the Pennsylvania Historical and Museum Commission, and other state agencies and the Federal Highway Administration (FHWA) to ensure conformance with regulations as well as to secure through the FHWA, federal aid on as many Department projects as possible. (http://www.dot.state.pa.us accessed on 9/8/11)." These four bureaus are centralized in Harrisburg. Highway Administration is also decentralized through 11 Engineering Districts.

The 11 Engineering Districts are geographically dispersed across the Commonwealth as shown on the Regional Map in Figure 35. Note that the Districts are

[64] This thesis is only concerned with Highway Administration.

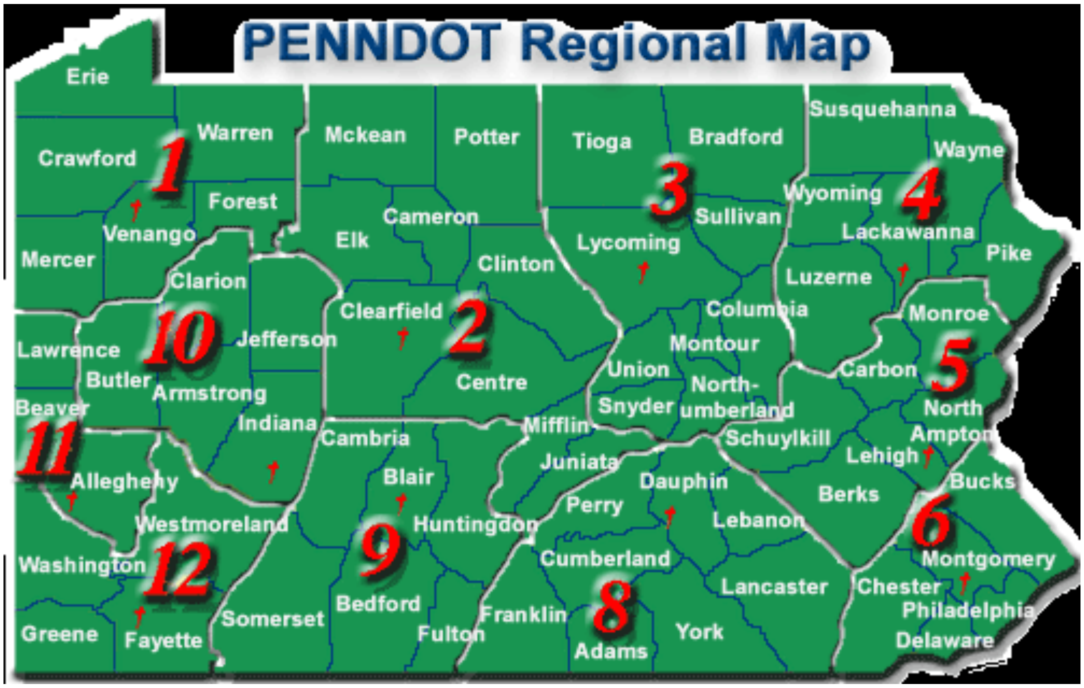


Figure 35 - PennDOT Regional Map displaying the 11 Engineering Districts.

numbered 1 to 12. There is no District 7. The Districts jurisdictionally include entire counties. The number of counties within a District varies form 3 in District 11 to 9 each in Districts 2 and 3. The role of the Districts is to localize engineering and maintenance functions. Bridge and road projects are designed and constructed under the direction of the Districts according to the standards set by the central bureaus in Harrisburg. Each District's CEO is designated as either the District Engineer or more recently, District Executive. Each District has an engineering staff capable of supervising and/or preparing bridge and road designs. The Districts also employ construction engineering staff as well maintenance, operations, traffic, geotechnical, and safety personnel. The Districts are also staffed to perform Right-of-Way functions, permitting (road use and access), materials control, quality improvement, surveying, municipal services, and utility coordination.

The following addresses PennDOT's current approach to program development and project delivery process and appears in the Design Manual, Part 1, *Transportation Program Development and Project Delivery Process,* Publication 10, dated September 2010.

> In order to adapt to a changing environment where land use and community needs are becoming even more dependent on transportation and vice versa, PennDOT has implemented a Transportation Program Development and Project Delivery Process intended to ensure that the limited transportation funding is:
>
> • Used to maintain existing infrastructure first;
>
> • Applied in a manner that requires smart land use decisions;
>
> • Focused on better use of existing capacity; realizing that adding capacity is not always the answer; and,
>
> • Programmed based on realistic project (design and construction) cost estimates; projects are designed to these estimated costs.
>
> During the initial transportation planning phases, PennDOT and its Planning Partners, typically the Metropolitan and Rural Planning Organizations (MPO/RPO), take responsibility for identifying potential transportation problems. The Planning Partners are asked to help develop project needs, identify potential alternatives, ensure environmental responsibility, and create a fundable transportation plan, which contains proposals and potential projects that will sustain and enhance the transportation network and our Commonwealth's communities.

4.2.2. NJDOT

The New Jersey Department of Transportation (NJDOT) operates, develops and maintains the State's public road system, including Interstate, State and Federal highways within the State. This includes a total of 2,324 miles of State-owned and operated roads. The majority of the major highways in the State fall under NJDOT jurisdiction. The exceptions include the New Jersey Turnpike (NJTPK), Garden State Parkway (GSP) and the Atlantic City Expressway (ACE), which are all toll facilities. The interstate toll bridges and tunnels also fall outside of NJDOT jurisdiction. NJDOT headquarters are located in Ewing, NJ. NJDOT employs approximately 3,850 people. The Department's CEO is the New Jersey Commissioner of Transportation, currently James Simpson. The current Deputy Commissioner is Joseph W. Mrozek.

Figure 36 – Map of New Jersey delineating the 3 Regions within NJDOT

There are essentially 7 functional units or divisions within NJDOT reporting to the Deputy Commissioner. These include Administration, Statewide Traffic Operations, Finance, Government & Community Relations, Capital Investment Planning &

Grant Administration, Operations, and Capital Program Management[65]. An Assistant Commissioner heads each division. The Assistant Commissioner for Capital Program Management is Richard Hammer, PE. There are 6 functional units within the Capital Program Management. These include Project Development, Right-of-Way & Access Management, Capital Program Support, Project Management, Design Services, and Construction Services & Materials. Capital Program Support includes Program Systems Management, Landscape Architecture & Environmental Solutions, and Value Management. Design Services includes Civil Design, Structural Design, and Regional Design & Surveying Services. The functional units within Capital Program Management operate centrally and regionally. NJDOT is further organized in to three Regions: North, Central, and South.

The North Region encompasses Bergen, Essex, Hudson, Morris, Passaic, Sussex, Union counties and portions of Warren County including Route 57 and north. The Central Region is comprised of Hunterdon, Mercer, Middlesex, Monmouth, Ocean, Somerset counties and portions of Warren County including Routes 22, 122, 173, 78 and including south of Route 57. The South Region contains Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, and Salem counties. Each Region is headed by and Executive Director. Each Region administers and in some cases executes the following duties Project Planning & Development, Construction, Project Management, Maintenance, Permits, Traffic Operations, Survey Services, Materials Inspection & Testing, Right-of-Way, Purchasing, Human Resources, and Equipment Service & Repair Center.

[65] Capital Program Management is of primary concern in this thesis.

NJDOT has refined and standardized the Project Delivery Process in an effort to optimize evaluation, planning, designing, and constructing capital projects[66]. The Department attempts to provide consistency and reliability in an effort to ensure that a quality product is created on time and at the lowest possible cost. This standard process provides a framework for all of NJDOT's service areas and guidance to project management staff. The NJDOT's Project Delivery Process aligns with FHWA's regulations and is designed to control and simplify the process under which Federal approval and funding is obtained. The Project Delivery Process consists of the Problem Screening Phase, Concept Development Phase, Preliminary Engineering Phase, Final Design Phase and Construction Phase. The following is an overview of the NJDOT Project Delivery Process described on the Department's website found at http://www.state.nj.us/transportation/ retrieved on 9/8/11.

NJDOT's Project Delivery Process begins with an evaluation of potential transportation problems in the Problem Screening Phase. During evaluation, NJDOT researches the problem statement to have a clear understanding of the problem and its impact. It determines how important that problem is relative to other transportation problems. These problems are then ranked by priority and importance. A primary goal of NJDOT is to make the best use of limited resources by investing in solutions that provide the greatest benefits to the transportation system on which New Jersey residents, businesses and visitors rely. Other considerations in the selection of potential projects include the type of work required and the geographical location. Taking into

[66] Project Delivery Process should not be confused with Project Delivery System or Method. The latter will be explained in depth in later in this chapter.

consideration the priority, type and location, NJDOT makes the best decision for the state and its taxpayers.

Project planning occurs during the Concept Development Phase. During this phase, NJDOT considers the problems associated with the project and looks at alternative solutions. An alternative is selected based on environmental impacts, constructability, cost effectiveness, how effectively the alternative addresses the project need, and if the project can be constructed in a timely manner. This selected alternative becomes the Preliminary Preferred Alternative (PPA). The Project Delivery Process ensures that the PPA addresses the original project need, has the lowest negative impact to the environment and the transportation system, and can be delivered in a timely manner and a reasonable cost.

Once NJDOT approves the PPA, it is further developed using industry standards and practices. During the Preliminary Engineering phase, NJDOT conducts an environmental analysis of the PPA and initiates project design work in support of the environmental document. Key products of the Preliminary Engineering Phase include the Project Management Plan, Preliminary Engineering Report, Design Exception Report (if necessary) and the Approved Environmental Document.

During the Final Design Phase, a set of detailed construction plans and specifications are developed for construction of the project. NJDOT's primary goal is to ensure that a quality design is developed so that a quality product can be built. In this phase, NJDOT also will secure the necessary permits to begin construction. The Project Delivery Process helps ensure all design decisions involve the right Subject Matter

Experts, the design will be constructible, the end result will address the original project need, and that there will be few changes required during the Construction Phase.

In the Construction Phase, the NJDOT focuses on minimizing impacts to the existing infrastructure and the traveling public. Utilizing various engineering disciplines, NJDOT also ensures that the contractor is building the project according to the design plans and specifications. The Project Delivery Process helps ensure that all work adheres to state and federal regulations.

The NJDOT uses the Project Delivery Process to guide work on transportation projects from the identification of a problem through final construction. The Project Delivery Process at NJDOT is constantly evaluated and improved based on lessons learned and best practices from other related industries.

4.2.3. DelDOT

The Delaware Department of Transportation (DelDOT) is the agency of the responsible for conceiving, construction, operation and maintaining the highway system in the State of Delaware. DelDOT's responsibilities include maintaining approximately 90% of the state's public roadways, snow removal, the Division of Motor Vehicles and the Delaware Transit Corporation (known as DART First State). The Delaware Highway Department was formed in1917 in response to the 1916 Federal Highway Act, which as previously stated, provided financial assistance for highway construction only to those states with an organized highway department in place. That early agency evolved into the present day DelDOT organization. DelDOT's headquarters are located in Dover. The current Secretary of Transportation is Shailen Bhatt.

There are essentially 8 functional areas under the Secretary including Transportation Solutions, Planning, Motor Vehicles, DART, Maintenance & Operations, Technical & Support, Finance, and Human Resources. Transportation Solutions is responsible for developing and delivery projects and is therefore the area of relevance to this thesis. "The mission of Transportation Solutions is to develop and construct safe, efficient and environmentally-sensitive engineering projects to meet identified transportation needs as guided by the Statewide Long-Range Transportation Plan (DelDOT http://www.deldot.gov retrieved 9/10/11)." Natalie Barnhart, PE is the current Director of Transportation Solutions; simultaneously serving as the Department's Chief Engineer.

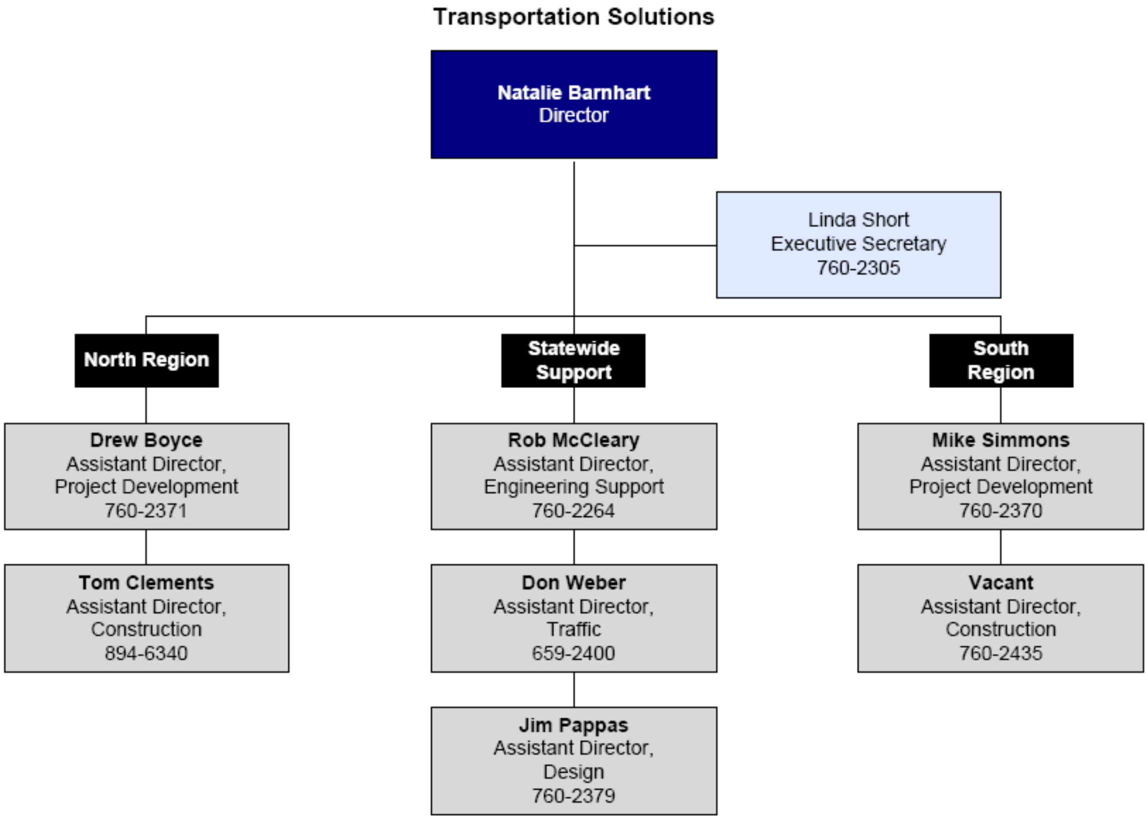


Figure 37 - Organization Chart of DelDOT's Transportation Solutions. The Director also serves as the Chief Engineer and reports to the Secretary of Transportation
Adapted from http://www.deldot.gov retrieved 9/12/11

The State is organized into North and South Regions for the purpose of project delivery[67]. The North is comprised of New Castle County north of Duck Creek and includes I-95 within the State of Delaware. The Department employs a modified matrix organizational structure to administer projects within the Region. Each Region employs Assistant Directors to administer Project Development and Construction responsibilities. Transportation Solutions includes a Statewide Support group covering Engineering Support, Traffic, and Design; each headed by an Assistant Director. Project delivery requires processes that are performed on both a centralized and de-centralized basis.

[67] The State is divided into 4 Districts; North, Canal, Central, and South to administer the Department's maintenance and operations functions.

DelDOT's project delivery process is summarized in the flowchart shown in Figure 38. The process begins with project initiation in the Concept Development stage.

The Concept Development includes defining the project scope; assessing the purpose and needs; developing, evaluating, and recommending alternatives; then compiling the concept plan for selected alternative. At this stage of development, the project must be deemed feasible from an engineering, economic and environmental impact standpoint. The project must also satisfy operational and maintenance requirements upon completion of construction. The project enters the Design Stage once it is confirmed that the project as configured can meet these requirements. Design begins with preparation of survey plans including the proposed vertical and horizontal controls and baselines. Close coordination with utility and right-of-way sections should be maintained from this point until completion of final plans. The next step is preparation and submittal of preliminary plans, followed by review.

Once the preliminary plans are approved, the Department holds a public workshop to introduce the project and solicit public feedback. Feedback from the public workshop along with utility and right of way information serve as input in preparation of the semi-final right-of-way plans. Acceptance of the semi-final right-of-way plans triggers preparation of the semi-final construction plans, the approval of which precedes preparation of final right-of-way plans; and ultimately the final construction plans. The review and approval of the final construction plans leads to packaging of the Plans, Specifications, & Estimate (PS&E). Upon final review and acceptance of the PS&E package, the project leaves the Design stage and enters the Procurement stage.

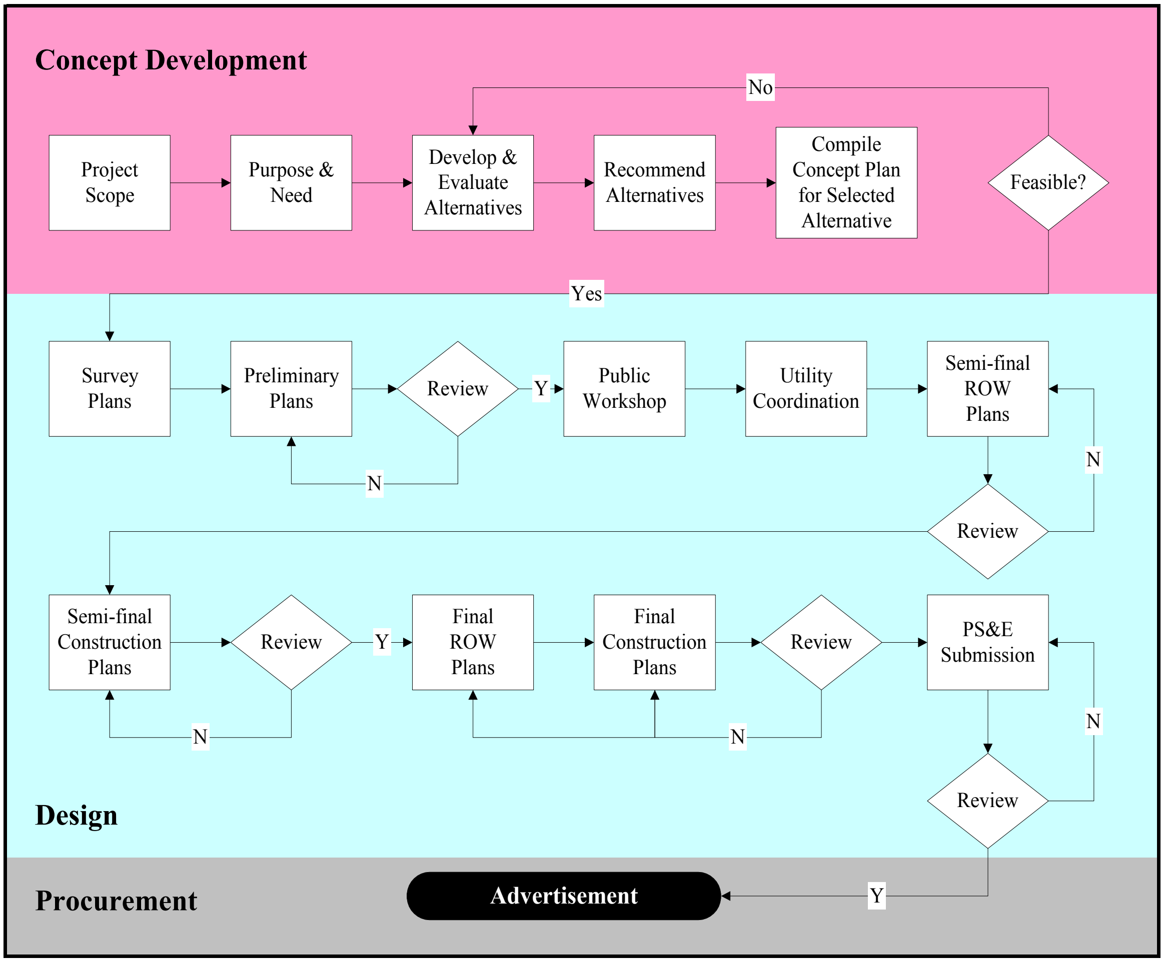


Figure 38 – DelDOT Project Delivery Process Flow Chart

4.2.4. MDSHA

The Maryland State Highway Administration (MDSHA or the SHA) is the state agency responsible for developing, constructing, and maintaining the freeway system in Maryland beyond the Baltimore City limits. The State Roads Commission (SRC) formed in 1908 was the original highway department in Maryland. The genesis of the State Roads Commission can be traced back to 1904 when highway survey functions were executed by the Maryland Geological and Economic

Survey, with the SRC assuming those duties in 1908 (http://www.msa.md.gov/msa retrieved 9/12/11). The MDSHA was formed in 1971 and assumed all of the State highway programs, which had been administered by the State Roads Commission up to that point.

The MDSHA is a division of the Maryland Department of Transportation (MDOT). MDOT is headquartered in Hanover, MD, while MDSHA has its headquarters in the City of Baltimore. Beverley K. Swaim-Staley is the current Secretary of Transportation and Neil Pedersen is the current MDSHA Administrator. MDSHA is centrally organized into three main divisions referred to as Offices with several subordinate functional offices. The three main offices include Finance, Information

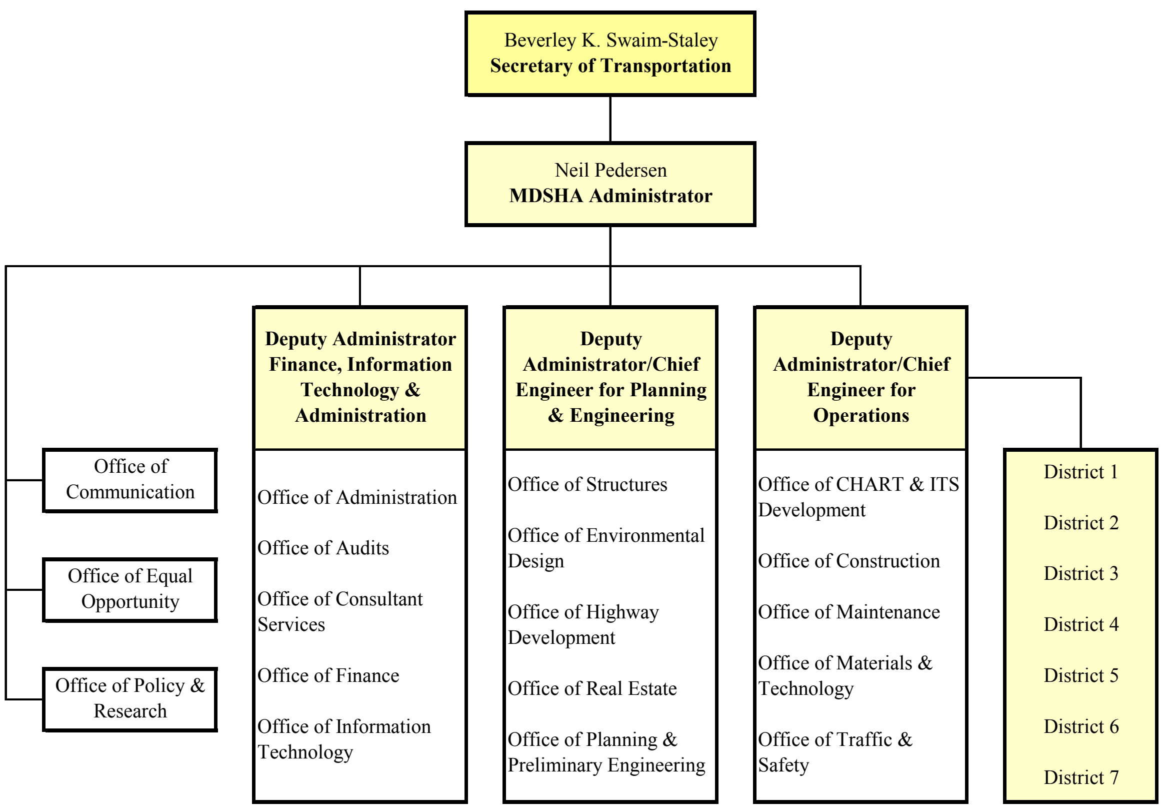


Figure 39 – MDSHA Organizational Chart

Technology & Administration; Planning & Engineering; and Operations. Planning and Engineering include the Office of Planning & Preliminary Engineering, the Office of Highway Development, the Office of Structures, the Office of Environmental Design, and the Office of Real Estate. Operations include the Office of Construction, Office of Maintenance, the Office of Traffic and Safety, Office of Materials & Technology, and the Office of CHART and ITS Development[68]. The Office of Policy & Research reports directly to the SHA Administrator.

MDSHA provides decentralized administration through its Districts offices. The State is divided into seven Districts. Each District includes divisions for traffic, construction, maintenance, and utilities coordination. The individual Districts also operate several maintenance shops—typically one per county. The Districts with headquarter locations and their

District No. -- Headquarters
Counties
District 1 -- Salisbury
Wicomico County Worcester County Somerset County Dorchester County
District 2 -- Chestertown
Cecil County Kent County Queen Anne's County Talbot County Caroline County
District 3 -- Greenbelt
Montgomery County Prince George's County
District 4 -- Lutherville
Baltimore County Harford County
District 5 -- Annapolis
Anne Arundel County Calvert County Charles County Saint Mary's County
District 6 -- La Vale
Washington County Allegany County Garrett County
District 7 -- Frederick
Frederick County Howard County Carroll County

Table 7 – MDSHA Districts

[68] "CHART" is an acronym for *Coordinated Highways Action Response Team* which provides incident response services throughout the State.

respective counties are listed in Table 7. A District Engineer heads each District. The District Engineer essentially represents the SHA in all public matters at the district level. The District Engineers also make recommendations to the central SHA office and coordinate District work with representatives of the FHWA, various offices within MDOT, other State agencies, local government, and the public at-large. The Districts oversee bridge and road construction projects with support from central offices including Planning & Engineering and the Office of Construction. Preconstruction project development is handled through the five offices under the main office of Planning & Engineering. The Office of Construction expedites highway construction and reconstruction projects in support of the Districts. The Office processes contracts, pays contractors, inspects construction projects, and establishes policies and procedures for projects within the State highway system.

The development and construction process is described in the guidelines titled Maryland Action Plan: Highway Project Development 2011. It includes a 4-phase process consisting of Planning that includes Administrative Preliminaries and Project Planning, final design, right-of-way acquisition, and construction. The process includes significant public involvement early and heavy inter-agency coordination throughout.

4.2.5. VDOT

The Virginia Department of Transportation (VDOT) is the state government agency responsible for transportation in the Commonwealth of Virginia. VDOT is responsible for developing, construction, operating, and the roads, bridges and tunnels in the Commonwealth. VDOT is a child agency of the Commonwealth Transportation Board. The State Legislature formed the State Highway Commission in 1906, which became the Department of Highways in 1923, the Department of Highways & Transportation in 1974, and finally VDOT in 1986 (http://www.virginiadot.org/about/resources/historyofrds.pdf retrieved 9/14/11).

VDOT is responsible for 57,867 miles of roads, 12,603 bridges, 6 tunnels, and 4 ferry services with a current annual budget of $3.38 billion. The organization employs approximately 7,500 full-time employees[69]. The current Secretary of Transportation is Sean T. Connaughton. The current Commissioner of Highways is Gregory Whirley, Sr. who is in charge of all highway operations in the Commonwealth. The Commissioner heads an organization with a functional structure organized into six groups namely System Operations, Policy and Environment, Administration, Planning & Programming, Finance, and Engineering. Each of these is headed by a Department Chief that report directly to the Commissioner. The Chief Deputy Commissioner, Inspector General, Director of Strategic Initiatives, and Enterprise

Figure 40 - Map of Virginia delineating the 9 VDOT Districts
Adapted from http://www.virginiadot.org retrieved on 9/14/11

[69] This is down from 10,380 in 2001 and 11,057 in 1964 (VDOT History of Roads retrieved 9/14/11)

Applications Office also report directly to the Commissioner. The organizational chart for the VDOT Highways is included in the appendices of this thesis. The Department's central headquarters are located in Richmond, VA. In addition to the centralized functions based in Richmond, VDOT is organized in nine districts to administer the decentralized functions of the Department. These include Bristol, Culpeper, Fredericksburg, Hampton Roads, Lynchburg, Northern Virginia, Richmond, Salem, and Staunton Districts as delineated on the map in Figure 40 and listed in Table 8. The districts are divided into 29 residencies and two district satellite offices, responsible for one to four counties each. Each of these Districts reports to the Chief Deputy Commissioner, currently Charles Kilpatrick, PE. The Public-Private Transportation Act (PPTA) Office and Information Technology also report to the Chief Deputy Commissioner. Malcolm Kerley, PE is the Chief Engineer.

Table 8 - Listing of the Nine VDOT Districts and the Counties and Cities that each represents

VDOT District Name (Location) **Counties** **Cities**
Bristol District **Counties** Bland, Buchanan, Dickenson, Grayson, Lee, Russell, Scott, Smyth, Tazewell, Washington, Wise and Wythe **Cities** Bristol, Norton
Salem District **Counties** Bedford, Botetourt, Carroll, Craig, Floyd, Franklin, Giles, Henry, Montgomery, Patrick, Pulaski and Roanoke **Cities** Bedford, Galax, Martinsville, Radford, Roanoke and Salem
Lynchburg District **Counties** Amherst, Appomattox, Buckingham, Campbell, Charlotte, Cumberland, Halifax, Nelson, Pittsylvania and Prince Edward **Cities** Danville and Lynchburg
Richmond District **Counties** Amelia, Brunswick, Charles City, Chesterfield, Dinwiddie, Goochland, Hanover, Henrico,[note 1] Lunenburg, Mecklenburg, New Kent, Nottoway, Powhatan and Prince George **Cities** Colonial Heights, Hopewell, Petersburg and Richmond
Hampton Roads District **Counties** Accomack Isle of Wight, James City, Northampton, Southampton, Surry, Sussex, York and Greensville **Cities** Chesapeake, Emporia, Franklin, Hampton, Newport News, Norfolk, Poquoson, Portsmouth, Suffolk, Virginia Beach and Williamsburg
Fredericksburg District **Counties** Caroline, Essex, Gloucester, King and Queen, King George, King William, Lancaster, Mathews, Middlesex, Northumberland, Richmond, Spotsylvania, Stafford and Westmoreland **Cities** Fredericksburg
Culpeper District **Counties** Albemarle, Culpeper, Fauquier, Fluvanna, Greene, Louisa, Madison, Orange and Rappahannock **Cities** Charlottesville
Staunton District **Counties** Alleghany, Augusta, Bath, Clarke, Frederick, Highland, Page, Rockbridge, Rockingham, Shenandoah and Warren Cities Buena Vista, Covington, Harrisonburg, Lexington, Staunton, Waynesboro and Winchester
Northern Virginia District **Counties** Arlington, Fairfax, Loudoun and Prince William **Cities** Alexandria, Fairfax, Falls Church, Manassas and Manassas Park

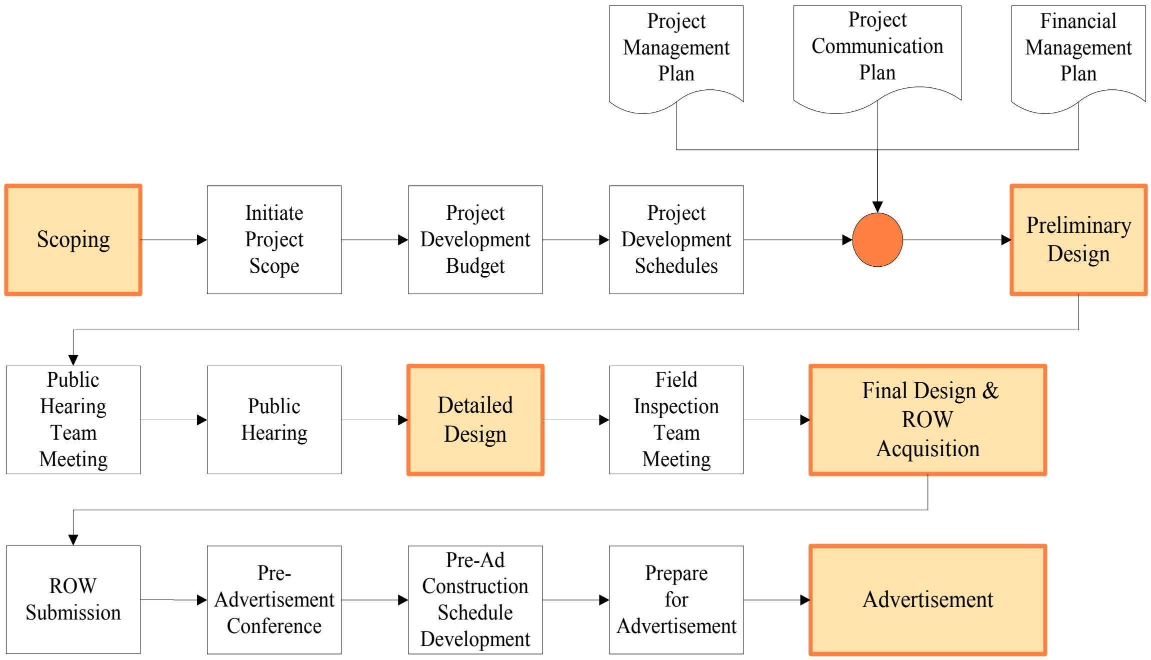


Figure 41 - Flowchart depicting VDOT's Project Development Process (PDP)

VDOT defines the project life cycle phases as Initiation, Development, Delivery and Closeout. The Project Development Process (PDP) formally describes the Development Phase. The PDP itself consists of 5 phases; Scoping, Preliminary Design, Detail Design, Final Design and ROW Acquisition, and Advertise Plans[70]. There are several steps within or between PDP phases as shown on the flowchart in Figure 41.

4.2.6. WVDOT

The West Virginia Department of Transportation WVDOT is the state agency responsible for all modes of transportation in West Virginia.

[70] The "Advertise Plans" phase is usually considered a procurement phase within the project life cycle. However, VDOT does not recognize a separate phase for procurement.

The Department of Transportation serves as the parent organization for seven subordinate agencies that are directly in charge of the various segments of the State's infrastructure. The Division of Highways is the agency of interest in this study.

The West Virginia Division of Highways (DOH) is the largest agency within the Department of Transportation. The Division of Highways is responsible for nearly all public roads within the State beyond the incorporated municipalities. The Division of Highways can trace its roots back to the State Road Bureau. In 1913, the West Virginia Legislature created the State Road Bureau, which was then replaced in 1917 by the State Road Commission (SRC) (http://www.millenniumhwy.net/wvroads/history.pdf retrieved 9/15/11). The WV Legislature changed the name of the State Road Commission to the Department of Highways in 1970 (http://www.millenniumhwy.net/wvroads/milestones.pdf retrieved 9/15/11)[71]. The Department of Highways was an autonomous agency until 1989 when it became the Division of Highways under the umbrella of the newly created WVDOT.

[71] Document titled West Virginia Highways: State and National Highway-Related Milestones

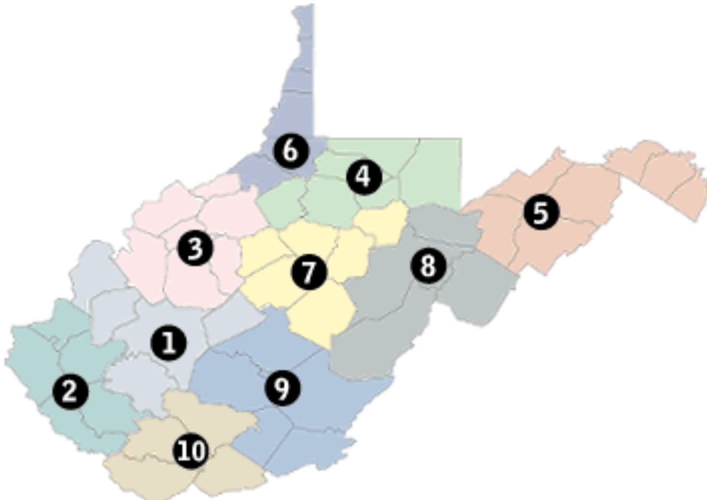


Figure 42 - Map of West Virginia delineating the 10 Highway Districts (Adapted from http://www.transportation.wv.gov retrieved on 9/15/11)

The Division of Highways is responsible for planning, engineering, right-of-ways acquisition, construction, reconstruction, traffic regulation and maintenance of more than 34,000 miles of State roads and 6,710 bridges. The Division of Highways employs more than 4,500 men and women and has its central headquarters in Charleston. The current Secretary of Transportation is Paul A. Mattox, Jr., PE and the current State Highway Engineer is Marvin G. Murphy, PE, PLS. Functions such as statewide planning and preliminary engineering are conducted centrally.

Table 9 – Listing of the Ten WVDOT Districts and the Counties that each represents

WV Division of Highways - Districts	
Counties	
DISTRICT 1	DISTRICT 6
Boone, Clay, Kanawha, Mason and Putnam	Brooke, Hancock, Marshall, Ohio, Tyler and Wetzel
DISTRICT 2	DISTRICT 7
Cabell, Lincoln, Logan, Mingo and Wayne	Barbour, Braxton, Gilmer, Lewis, Upshur and Webster
DISTRICT 3	DISTRICT 8
Calhoun, Jackson, Pleasants, Ritchie, Roane, Wirt and Wood	Pendleton, Pocahontas, Randolph and Tucker
DISTRICT 4	DISTRICT 9
Doddridge, Harrison, Marion, Monongalia, Preston and Taylor	Fayette, Greenbrier, Monroe, Nicholas and Summers
DISTRICT 5	DISTRICT 10
Berkeley, Grant, Hampshire, Hardy, Jefferson, Mineral and Morgan	McDowell, Mercer, Raleigh and Wyoming

The State is divided into ten districts charged with administering decentralized activities including project delivery, operations, and maintenance. Table 9 lists the districts along with the counties that each represents. Figure 42 is a map of West Virginia upon which the districts are delineated. A District Engineer or District Manager heads each district. All ten districts are comprised of staff dedicated to design, construction, maintenance, traffic engineering, right-of-way, and permits. Some sections include utility, materials, and environmental coordinators.

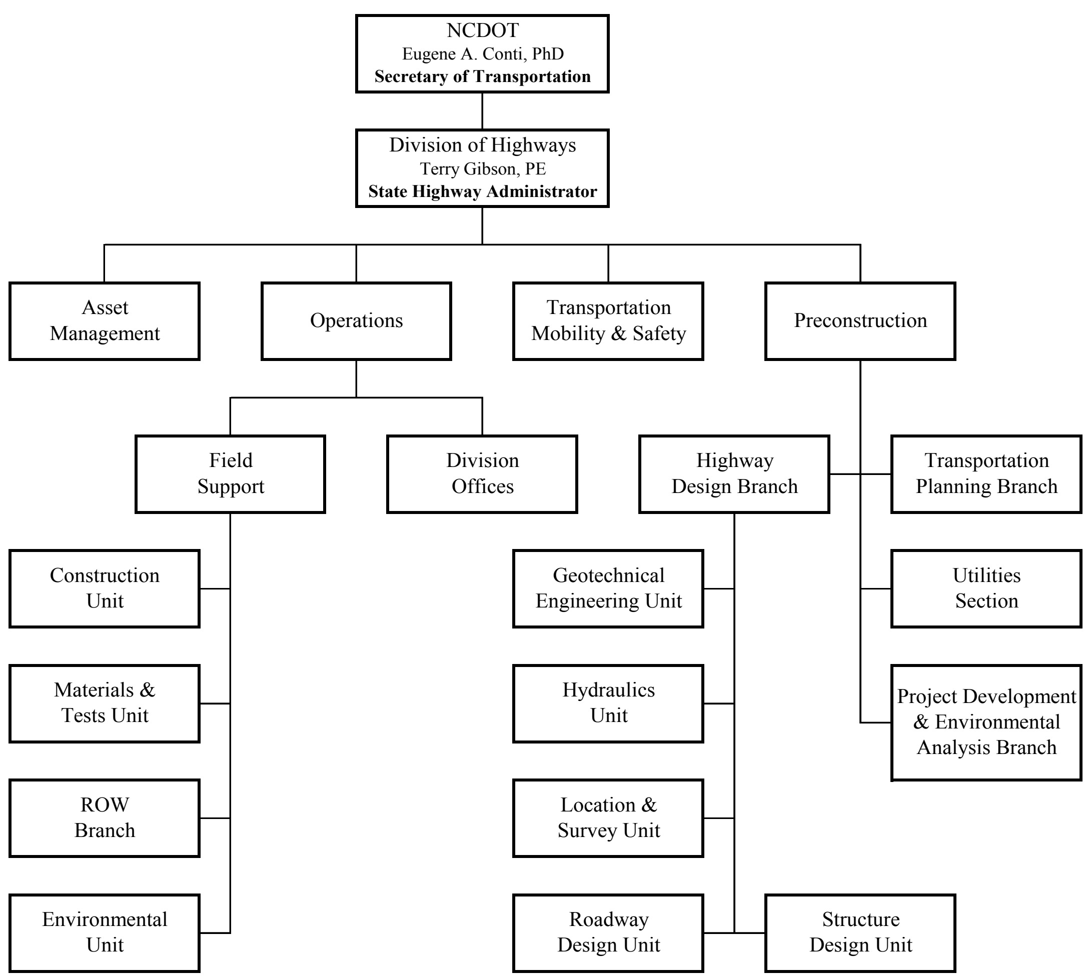
4.2.7. NCDOT

The North Carolina Department of Transportation (NCDOT) is the state agency responsible for transportation infrastructure in North Carolina. There are seven divisions within the NCDOT including Aviation, Public Transportation, Bicycles/Pedestrians, Rail, Ferry, Turnpike, and Highway. The North Carolina Department of Transportation has its roots in the State Highway Commission, originally formed in formed in 1915. The Department of Motor Vehicles (DMV) was established in 1941 by the General Assembly. The Executive Organization Act of 1971 subsequently combined the State Highway Commission and the Department of Motor Vehicles to create the N.C. Department of Transportation and Highway Safety. In 1979, "Highway Safety" was eliminated from the Department's name when the Highway Patrol Division was reassigned to the then newly created Department of Crime Control and Public Safety (http://www.ncdot.gov/about/structure/ retrieved 9/15/11).

NCDOT operates under a fairly complex organizational structure. The various units under the NCDOT umbrella are aligned according to six strategic functions. These include Organization, Monitoring, Communication and Control; Transportation Strategy and Investment Analysis; Transportation Business Administration; Process Management; Transportation Program and Asset Management; and Transportation Program Delivery.

Organization, Monitoring, Communication and Control is an overarching function which involves overseeing and evaluating the day-to-day operations to ensure efficiency, effectiveness and accountability. This includes oversight and management of departmental operations. It also includes risk management and auditing functions, as well as operational performance and best practices across the Department. Transportation Strategy and Investment Analysis develops, monitors, and manages strategic plans and investment alternatives according to long-range multi-modal transportation needs. Transportation Business Administration provides the day-to-day business administration services. Process Management provides the technical services required to improve delivery of projects, programs, services and initiatives. Transportation Program and Asset Management includes the day-to-day central management, expertise and administration of highway and multi-modal transportation programs. Transportation Program Delivery oversees the day-to-day delivery of the projects, programs, services and initiatives within the Department. The formal NCDOT Organizational Chart is included in the Appendices of this thesis.

The Division of Highways is responsible for planning, design, construction, maintenance, and operations of the State highway system; currently second largest state maintained highway system in the nation (http://www.ncdot.gov/ retrieved 9/15/11). The Division of Highways is responsible for building and maintaining the, incorporating over 78,615 miles of highways and 18,540 bridges. The Division of Highways consists of four functional areas including Asset management, Operations, Transportation Mobility & Safety, and Preconstruction. In terms of the NCDOT structure, Division of Highways Operations falls under Transportation Program Delivery. The other three areas are under Transportation Program & Asset Management. Operations and Preconstruction are the two areas of interest considered in this study. Figure 43 shown below is a synthesized organizational chart for the Division of Highways.



Operations central functions come under Field Support, which includes the Construction Unit; Materials and Tests Unit; Roadside Environmental Unit; and the Right of Way Branch. The Construction Unit provides oversight and support of highway construction projects executed by the Division Offices. The Construction Unit works closely with the Federal Highway Administration and the 14 Division Offices. Similarly, the Materials and Tests Unit, Right-of-Way Branch, and Roadside Environmental Unit provide centralized support to the Division Offices and assure compliance with Department standards. Decentralized functions are handled the Division Offices.

There are 14 Division Offices covering the 100 counties of North Carolina. Figure 44 is a map of North Carolina delineating the Division Offices. Table 10 is a listing of the Division Offices and the counties they serve. The Division Offices are further divided into Districts for operations and maintenance and Resident Engineers Offices for Construction. Each Division is headed by a Division Engineer, each District by a District Engineer, and each Resident Engineers Office by a Resident Engineer. Each of these Engineers is often supported by one or more Assistant Engineers.

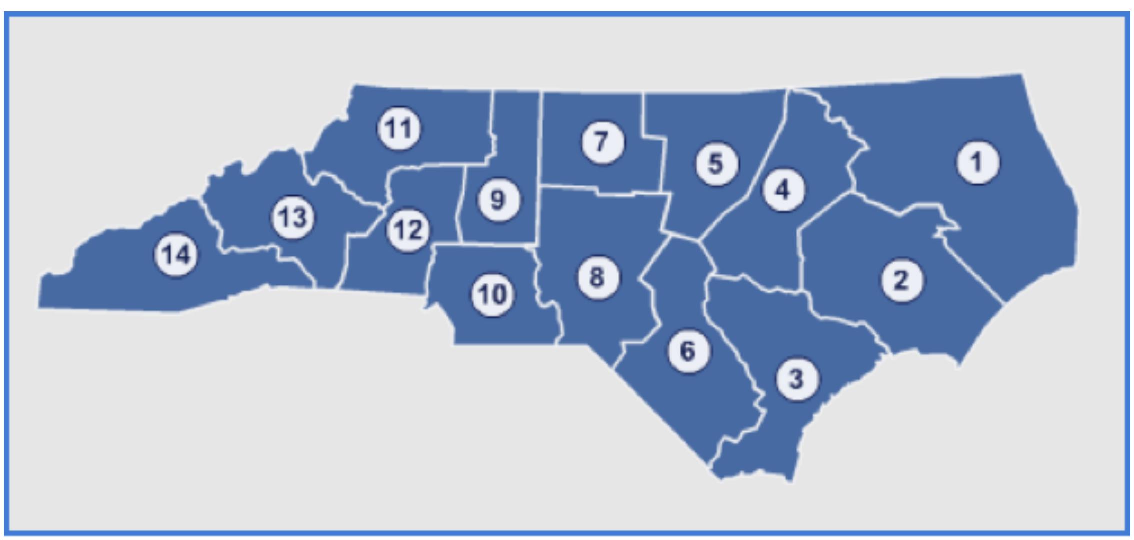


Figure 44 – Map of North Carolina delineating the 14 Division Offices

Table 10 - Listing of the 14 NCDOT Division Offices and the Counties each represents

NCDOT Division of Highways - Division Offices
Counties
Division 1 Bertie, Camden, Chowan, Currituck, Dare, Gates, Hertford, Hyde, Martin, Northampton, Pasquotank, Perquimans, Tyrrell, and Washington
Division 2 Beaufort, Carteret, Craven, Greene, Jones, Lenoir, Pamlico, and Pitt
Division 3 Brunswick, Duplin, New Hanover, Onslow, Pender, and Sampson
Division 4 Edgecombe, Halifax, Johnston, Nash, Wayne, and Wilson
Division 5 Durham, Franklin, Granville, Person, Vance, Wake, and Warren
Division 6 Bladen, Columbus, Cumberland, Harnett, and Robeson
Division 7 Alamance, Caswell, Guilford, Orange, and Rockingham
Division 8 Chatham, Hoke, Lee, Montgomery, Moore, Randolph, Richmond, and Scotland
Division 9 Davidson, Davie, Forsyth, Rowan, and Stokes
Division 10 Anson, Cabarrus, Mecklenburg, Stanly, and Union
Division 11 Alleghany, Ashe, Avery, Caldwell, Surry, Watauga, Wilkes, and Yadkin
Division 12 Alexander, Catawba, Cleveland, Gaston, Iredell, and Lincoln
Division 13 Buncombe, Burke, Madison, McDowell, Mitchell, Rutherford, and Yancey
Division 14 Cherokee, Clay, Graham, Haywood, Henderson, Jackson, Macon, Polk, Swain, and Transylvania

4.3. Synopsis of Project Delivery Systems

Project Delivery Systems are the processes by which a project is designed and built for an owner from conceptualization through commissioning, including the sequencing and phasing. Project Delivery System refers to the mechanics involved in developing a design to meet an owner's need and substantively transforming a concept into a physical reality. There are formal definitions for project delivery system (or method) promulgated by various industry associations including the American Institute (AIA), American Society of Civil Engineers, and the Associated General Contractors of America (AGC)[72]. The AGC formally defines the project delivery method as "the comprehensive process of assigning the contractual responsibilities for designing and constructing a project . . . a delivery method identifies the primary parties taking contractual responsibility for the performance of the work" (Associated General Contractors 2004).

There are essentially three major project delivery systems including design-bid-build, design-build, and Construction Manager At-Risk (Touran et al 2008). There is a multitude of variants and spin-offs from these essential methods. Some of these hybrids include financing, operation and maintenance of a constructed facility. All of these assign or reflect the roles of the owner, designer, and constructor. The individual systems also exhibit distinct sequences. Distinguishing features across the various systems includes the formation of contracts between the project's owner, designer, and constructor. Contractual relationships form the basis of the delivery systems. Contracts are the instruments that establish the relationships between the parties, define the duties

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[72] The word "system" is loosely interchangeable with the word "method" when discussing project delivery. "System" appears to be preferred among most in the AEC community.

and roles, and allocate risks. AIA, AGC, Consulting Engineers Council (CEC), Design-Build Institute of America (DBIA), Construction Management Association of America (CMAA), and Engineers Joint Contract Documents Committee (EJCDC) have developed model contracts tailored to specific delivery systems. Contracts, like the project delivery systems they define are considered either traditional or alternative. The term "innovative contracting" appears to be giving way to the term "alternative contracting" as these systems become more common and accepted in practice. Contracts can be further classified by method of award, method of selection, and method of pricing.

4.3.1. Contract Classification by Method of Pricing, Award, and Selection

Construction work is executed under a binding contract between an owner and constructor. The term "constructor" is preferred here since that entity can take one of at least three different forms. The other two major entity forms would be a construction manager at-risk and design-builder, depending upon the project delivery method. The term "contractor" carries broad meaning as well as some specific connotations. The term "contractor" can mean a general contractor whose assumes full responsibility for the work while in direct contractual privity with the owner[73]. The general contractor holds the ultimate contractual position referred to as the prime contractor. The prime contractor is responsible for all contract work, regardless of how much or little work they physically perform themselves. The prime contractor bears the performance and cost risks associated with the contract. Most contracts in public highway construction require that

[73] Privity is a key concept in common law which holds that one may not be obligated to anyone other than those with whom one has entered into a contract (Bockrath and Plotnick 2011)

the general (prime) contractor self-performs the work for 50% or more of the contract dollar value.

The term “contractor” could also refer to a specialty or trade contractor that performs a portion of the work under subcontract to the general contractor. The lines of privity in this case run between the general contractor and the subcontractor. The subcontractor in this case is referred to as a first tier subcontractor. Privity does not exist between the owner and the subcontractor(s). Both parties must follow the formal lines of communication, which flows in both directions through the general contractor. The subcontractor must submit RFIs, required submittals, and claims through the general contractor. Direction, resolution of problems and conflicts, and payment must flow down from the owner through the general to the subcontractor(s). Contracting in commercial building work and other private sectors of construction allow for second tier and lower subcontractors. That is typically not the case for public highway contractors. In other words, a subcontractor cannot usually subcontract any part of their work to another subcontractor on highway projects. Material suppliers or fabricators occupy the second tier as subordinates to subcontractors. Other suppliers are naturally lower tier depending upon their position in the supply chain.

Construction contracts address many issues of importance to both parties. A comprehensive contact expresses all of the duties and responsibilities of both parties. It defines the arrangement by which parties are compensated. Construction contracts can be defined by type in terms of the method of award, method of selection, and method of pricing (Figure 48 on Page 210). The method of award is either based on competition or negotiation. Negotiated contracts are found widely in segments of the private sector.

Negotiation as a method of award is often used on projects of large size and great complexity. Private owners are free to negotiate with organizations that they trust and value. These owners may value expertise and integrity of a particular contractor and can award a contract without competition that may otherwise exclude that contractor from the work. Whereas private owners are free to negotiate with vendors and contractors, public owners including highway agencies are typically bound by state and federal procurement laws to award contracts through some type of competitive process. Only in the most extreme circumstances do public highway agencies use negotiation as a method of award.

Competition in the public arena is intended to be transparent and open to public scrutiny. All competitors for a contract start with a level playing field. The premise behind transparent, open, public competition is that the public best interest is best served through such processes. Public work requires formal advertising sufficiently ahead of contract award. It mandates that contract award strictly in accordance with the selection criteria; usually lowest responsive, responsible bidder. The method of selection is connected to the method of award. Method of selection is also referred to as the procurement process. It defines the process that serves as the basis of award for contracts awarded through competition. The three main methods of selection include bidding, qualifications-based selection, and best-value selection. It is in effect a subclass of the method of award. There are many permutations of these methods. However, this thesis will only include a brief overview of the three main methods of selection.

Competitive bidding is the method of selection in which the lowest responsive, responsible bidder is awarded the contract. Sealed bids are opened publicly at a designated time revealing the apparent low bidder. The bid proposals are further scrutinized to confirm that the lowest bid is responsible and responsive. "Responsible" means that the bidder meets the minimum qualifications required of all prospective bidders. Responsibility determinations focus on whether the contractor has the necessary technical, managerial, and financial capability and integrity to perform the work at stated in the RFP or similar public advertisement. The intension is that a "responsible" bidder is a contractor that is capable of undertaking and completing the work in a satisfactory fashion. Public highway agencies provide a prequalification process covering different types of work. Bidders must typically be prequalified prior to formal bid submission.

Prequalification of bidders prior to soliciting is standard procedure in public highway agencies. The protocol requires that prospective bidders provide evidence of satisfactory previous experience and financial stability. Advanced or specialized prequalification may be required as dictated by the magnitude and nature of the work. Prequalification is also intended to level the playing field by eliminating unqualified contractors that could underbid the field of qualified competitors. In addition to payment and performance bonds, bidders are generally required to provide bid bonds or some other securities to guarantee that if deemed to be the lowest responsive, responsible bidder, they will execute the contract.

Responsiveness differs from responsibility, as it focuses on whether the bid, as submitted, is an offer to perform the exact tasks listed in the bid invitation and whether acceptance will bind the contractor to perform in strict conformance with the invitation. Failure of a contractor to carefully comply with all the requirements for competitive bidding may result in the bid being declared "nonresponsive," or if an award has been made, may render the contract voidable or prevent the contractor from recovering full compensation for work performed. Examples of bidder being nonresponsive include submission of irregular proposals. Proposals are considered irregular and summarily rejected as nonresponsive for any number of reasons. This could include submitting the proposal on a form or in a format if other than that approved, or if the form is altered or any part detached or incomplete.

A nonresponsive bid may be deemed so if it contains unauthorized additions, conditional bids, or irregularities of any kind that may tend to make the proposal incomplete, indefinite, or ambiguous. Also, it is nonresponsive if the bidder adds provisions reserving the right to accept or reject an award. Irregular proposals includes those where a bidder specifies a unit price of zero or fails to provide a unit price for every pay item indicated except when authorized to do so. A proposal that is materially unbalanced or not properly signed is considered irregular and unresponsive. Failure to meet the specified DBE (Disadvantaged Business Enterprise) requirements including the necessary documentation will also be deemed nonresponsive. There many other situations that can render a bid nonresponsive, with most being explicitly stated within the contract documents.

. Qualifications-based selection is the standard procedure for selecting and retaining design professionals used in both private and public work. The method is a competitive procurement approach that emphasizes quality attributes. It is the routine method used by highway agencies to procure the services of design engineering firms. It is also the standard method of procuring professional services for construction engineering and inspection. The Federal “Brooks” Law (P.L. 92-582) enacted in 1972 codified qualifications-based selection process for A/E services into federal law. State procurement laws typically include mini Brooks laws in their regulations. The premise behind qualifications-based selection is that the public's best interest is served when securing professional services. Engineering design and construction services are considered professional services; not commodities. Engineering professionals are expected to provide a high level of technical expertise, innovation, expert judgment, and a high degree of professional competence. The analogy is made to the medical profession, where patients place quality over cost in choosing a health care provider.

Best value selection is a hybrid between qualification-based selection and low bid. It is a process employed to procure the most advantageous offer by considering and comparing factors in addition to cost or price. The method provides flexibility in procurement through tradeoffs, which the owner makes among the cost and non-cost factors to award the contract to the firm, or contractor that will provide the agency the greatest or best value for the public's money. Evaluation factors considered by the agency could include the value of contract time, quality criteria, past safety performance, and other metrics based on performance record. Chapter 5 of this thesis includes an expanded discussion and example of best value procurement as implemented by the Florida Department of Transportation (FDOT).

Figure 45 - Lump-sum Bid Price Development

The method of pricing dictates the format for compensation. There are three primary or common methods of compensation and several variants from these forms. These include fixed price, reimbursable or cost plus, and guaranteed maximum price (GMP). Fixed price methods include lump sum and unit price. These methods require that bidders submit fixed prices, which serve as the basis of payment upon execution of the project work. Lump sum is the traditional, single fixed price method. The bidder submits a single predetermined price that includes profit, overhead, and all other costs associated with completing all contract work. This method carries the greatest risk to contractor resulting in a high markup; i.e. the greater the risk, the higher required rate of return. Therefore, it is best suited when the scope of work including the quantities are fixed and well understood by both parties. It is the most common form of pricing outside of heavy construction.

The other form of fixed pricing is the unit price contract. This is the type commonly applied to highway projects. The designer prepares a list items from what is referred to as the “Engineer’s estimate”. The list should include all of the items of which the project is comprised. Commonly referred to as “line items”, these can be standard or special items. Examples of standard items for a roadway project include the various classes of excavation such as common excavation, trench excavation, structure excavation, muck excavation, and rock excavation. Examples of a special item include relocation of an historic monument, unique wetland vegetation, or decorative lighting. The designer states the unit and lists the estimated quantity for each item. In the case of excavation, the unit in which the quantity is measured is cubic yards (CY). There are several other units, which apply to the various line items based on length, area, volume, or weight.

Length units include linear feet (LF) or meters (M), area in square feet (SF), square yards (SY), or acres (Ac) for English imperial units and square meters (M2) and hectare (Ha) for metric units. The cubic meter (M3) is the metric volume corresponding to CY. A volumetric unit of measure peculiar to roadway, airstrips, and sitework is square yard-inch (SY-in). One SY-in is a three-foot square area, one inch thick. The unit is typically applied to subbase line items. Units of weight associated with various line items include pounds (lb) and tons. The corresponding metric units are kilograms (kg) and tonne (t). An old unit that remains in use is the hundredweight (CWT), which is one hundred pounds in the United States[74]. It is often used as a unit of measure for structural steel. A line item unit can also be expressed as a lump sum (LS) meaning that the item does not get measured for payment but the price should encompass the entire quantity associated with the item. Examples of line items that can be expressed as LS might include maintenance of traffic, removal of structures and obstruction, and initial expense.

The bid form includes a list of all line items necessary to complete the project. The bidder assigns a unit price to each line item and completes the cost extension for each by simply multiplying the unit price by the estimated quantity. The bidder then summarizes the cost extensions for all of the line items to arrive at a final bid price. The unit price quoted for a line item should include all direct and indirect costs associated with that item. Furthermore, each line item should have an apportioned amount to cover

[74] The definition used in the United Kingdom is different from that used in North America. The long hundredweight is defined as 112 lb, which is the definition used in the imperial system. The short hundredweight is 100 lb used in North America.

project (job) overhead, general overhead, profit, bond premiums, taxes, contingency, and any other cost the must be recovered through mark up. While the unit prices are fixed, the quantities generally are not. They are subject to variance; with the final quantity being measured in the field after the work is deemed to be in reasonably close conformance with the plans and specification. Actual cost to the owner will vary with actual quantities placed. This method is best used when the details and general character of the work are known, but quantities are subject to variation. There is obviously heightened risk to the owner due to the uncertainty of accuracy of the estimated quantities. Another risk is the potential for unbalanced bids.

A bid is deemed materially unbalanced when it is based on prices significantly lower than cost for some items and prices which are significantly inflated in relation to cost for other items. Such a bid will often not result in the lowest overall cost to the owner even though it may be the apparent low bid. Unbalanced bidding is done for two reasons and in two ways. The first is to front-end load the line items that are completed and paid early in the construction timeline in order to enhance the constructor's cash flow. The difference between the constructor's expenses and revenue through most of construction is a negative value known as the "overdraft". The overdraft is the amount that the constructor must finance or is an opportunity cost. The bidder will inflate early action items and underbid items that come later in the project in an effort to reduce the overdraft while ultimately covering costs. This gambit is not without risk to the bidder.

The other form of unbalanced bidding is when the bidder recognizes an error in the quantity and takes advantage by submitting a unit price that is significantly higher or lower than the actual cost plus reasonable markup. In an error in which the proposed quantity is grossly over-estimated, an educated bidder can submit a unit price that is significantly lower than actual cost knowing that the final quantity will be lower than the proposed quantity price. In doing so, the bidder places themselves at a competitive advantage that will not translate into the lowest cost for the owner.

Even more injurious to the owner is the case in which the quantity is significantly lower than will actually be required. A bidder taking advantage of such an error will submit a substantially higher unit price knowing that the final quantity and thereby the final payment will significantly exceed the expected amount. The crafty bidder will not be rendered less competitive by an inflated unit price if the proposed line item represents a small portion of the project. They will instead enjoy a windfall at the public's expense. Thus bids that can be proven to be materially unbalanced are deemed nonresponsive. However, this is usually very difficult for an agency to prove.

Reimbursable or more commonly cost-plus pricing is not based on fixed prices. Instead, the constructor agrees to perform the work for a fixed or variable fee covering profit and home office costs, i.e. general overhead. Field costs are reimbursable at actual costs. It is used when the nature of the work or physical conditions is unpredictable or the scope is unknown or difficult to define. It is rarely used for original contract pricing for highway construction. The rare exceptions are in the case of emergency reconstruction projects. However, public highway agencies frequently use cost-plus pricing in a form referred to as a "force account" for work added to a contract. Each agency has their own format, which prescribes allowable markups in addition to reimbursing approved direct costs.

All cost-plus contracts depend on cooperation between the owner and contractor. Comprehensive record keeping and timely evaluation are extremely critical. Detail records of labor hours and salaries, material and equipment must be maintained and verified on a daily basis. This often requires supplemental field staff on both sides to accurately track all aspects of the work. There are many variations of cost-plus contracts, three of which will be addressed. Two others, GMP and Target Estimate are actually hybrids. The three types of cost-plus that will be address here include cost plus fixed %, cost plus fixed fee, and cost plus variable %. This section also includes a discussion of GMP and target estimate pricing.

Cost plus fixed % is most advantageous to the contractor, but poses the most risk to the owner. Typically, the fixed % markup is based on portion or all of the reimbursable costs. It's used in construction involving new technology or extremely pressing needs such as an emergency reconstruction. The owner assumes all of the cost risk. Contractor cooperation is usually very high under the cost plus fixed % pricing. There is little or no incentive for cost savings.

Cost plus fixed fee is a pricing method used frequently by public highway agencies to procure engineering and other professional services. Highway agencies select consultants through the qualifications-based selection process and enter into negotiations with the successful consultant to set the fixed fee and cost limits. Cost plus fixed fee is more favorable to the owner than cost plus fixed % since it provides more incentive for cost savings. In fact the consultant or contractor has an incentive for timely completion. The owner and contractor or consultant more equitably shares risk.

Cost plus variable % is a less common method that can also be structured as an equitable arrangement for both sides. Also called "sliding scale %" the method is intended to keep the fee in line with type and volume of work. The fee % typically becomes progressively smaller on work that is repetitive, requires little or no re-engineering, re-planning, or additional layout. It also accounts for the advantage gained through the learning curve.

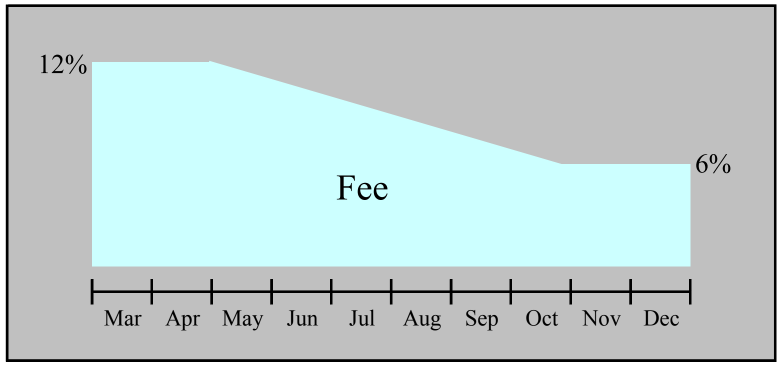

Figure 46 - Cost Plus Variable % a.k.a Sliding Scale %

Guaranteed maximum price or GMP is used with well-defined scope of work, typically on commercial building projects where the mode of delivery is CM@Risk or design-build. GMP is particularly suitable for a turnkey operation. Theoretically, the CM or design builder assumes all risk. Unfortunately, that is rarely the case in practice <citation>. A GMP is also referred to as a Not-To-Exceed Price (NTE or NTX) contract is essentially a cost-plus contract. The difference between this and other cost-plus structures is that a detailed estimate resembling a fixed unit-price line item tabulation is made and essentially forms the basis of payment.

In the case of the GMP, the contractor is compensated for actual costs incurred plus a fixed fee subject to a ceiling price. The inclusion of a ceiling makes GMP similar to a fixed contract. The constructor bears the cost of overruns, unless the GMP is adjusted through formal change order. An upward adjustment should only be made in response to an increased scope of work, not as a result of cost overruns, errors, or omissions. The owner retains savings from cost under runs. This is clearly different from a fixed-price contract where cost savings belong to the constructor and add to his profits.

Target estimate pricing is similar in some ways to a GMP. It may be based on dollar amounts, man-hours, schedule, or a combination. Costs are tracked as with any reimbursable contract. A predetermined negotiated markup is usually applied along with a target, floor, and ceiling. The two parties also negotiate the sharing split, usually 50-50. Cost savings below the target or the owner and the contractor share overruns above the target. Cost under runs increase contractor profit, overruns decrease profit.

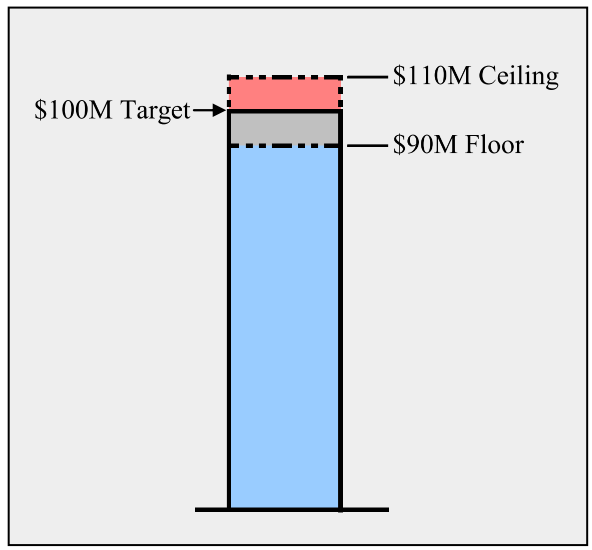

Figure 47 – Target Estimate Example

In the example shown in Figure 46, the target estimate value is $100 million with ceiling value of $110 million and a floor of $90 million. Assume a 50-50 split for this example. If the contractor completes the project at $90 million, then he receives $95 million payment; essentially earning a $5 million bonus. The owner is paying $5 million more than the cost, but also $5 million less than the target; thus saving that amount from the expected expenditure. If the final cost is $110 million, the contractor receives $105 million. Total amounts above the ceiling and below the floor can be addressed various ways.

The usual treatment for an overrun above the ceiling is no additional payment. In this example, the maximum payment to the contractor would be $105 million. If the total cost came in at say, $85 million, the contractor would receive $90 million final payment. That is the total cost plus 50% of the difference between the target value and the floor amount. The apportionment of risk in this type of pricing is largely based on the quality of the estimate. This type of pricing is never used in conventional highway contracting, but is foreseeable in innovative contracting such as public-private partnerships and others that employ innovative financing.

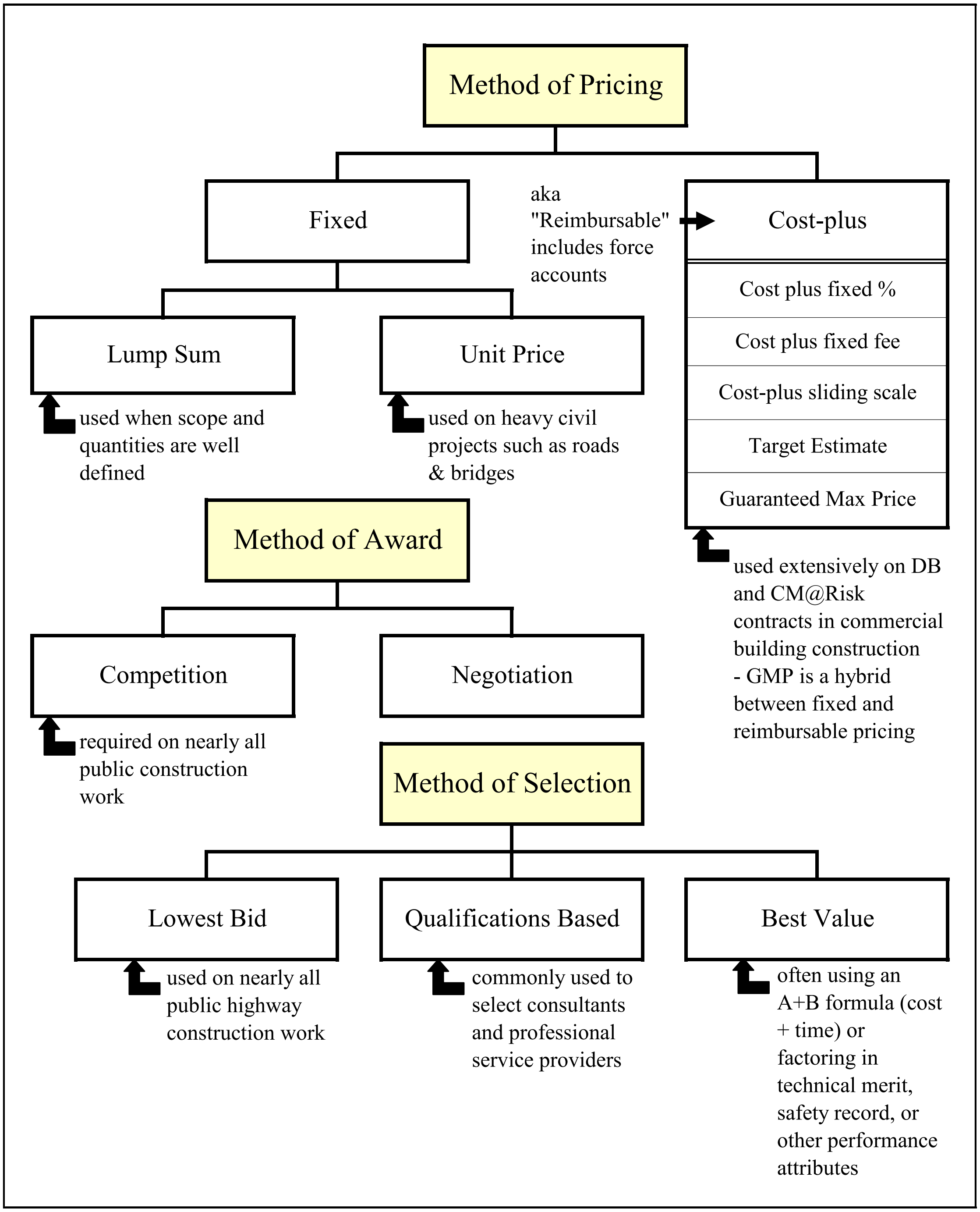

Figure 48 - Chart depicting the Methods of Pricing, Award, and Selection

4.3.2. Traditional Design-Bid-Build

Traditional design-bid-build is the long-standing standard method of project delivery in the highway industry and most other sectors and segments served by the Architectural-Engineering-Construction (AEC) community. DBB is a linear sequential process in which an owner secures an architectural and/or engineering professional to develop and complete the design and prepare the contract documents. In the case of highway projects,

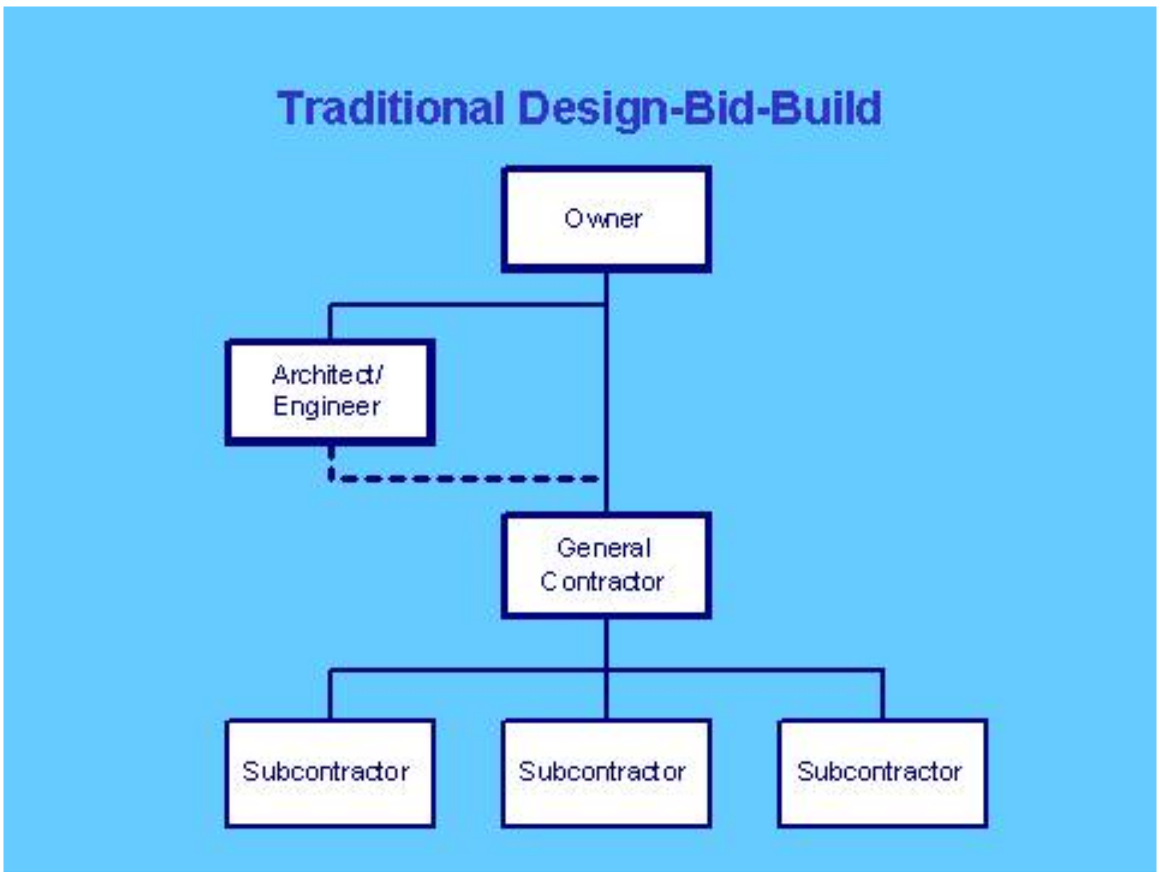

Figure 49 - Organization Chart for Traditional Design-Bid-Build

this includes than plans, special provisions, and all non-standard documentation. An alternate to this approach is for the highway agency to complete the design in-house with its own engineering staff. This approach is normally reserved for smaller, less complex projects. The more common approach is for the selected design consultant to develop the design under agency review and final approval. The design may be completed in stages tagged preliminary or final design. In any event, the point is that the design is 100% complete before proceeding to the next phase, which is procurement.

Procurement or the "bid" phase begins with formal advertisement of the project. Public highway agencies use regular media outlets to advertise upcoming projects. The typically use the same outlets for all projects to assure exposure to prospective bidders. Large project may receive greater exposure beyond the local and regional coverage given to most projects. The advertisement will include the name and brief description of the project; the cost of the plans and specifications and location from which these can be purchased; date, time, and location of the bid opening; and any special instruction to bidders.

All bidders are required to view the site of the proposed work, examine the contract documents, and review all general notices and applicable requirements prior to submitting a proposal. "If no site investigation is performed, the bidder assumes responsibility for all site conditions that should have been discovered had a reasonable site investigation been performed (DelDOT 2001)." Submission of a proposal is considered evidentiary that the bidder "is aware of and accepts the conditions to be encountered in performing the work and the requirements of the proposed Contract." Bidders should examine all contract documents including the plans, specifications, special provisions, supplemental specifications, and general notices. These can include boring logs and other geotechnical records of subsurface investigations. These can also include permits such as the 404 that the owner has obtained from the USACOE or other prevailing regulatory agency, the conditions of which the successful bidder must comply. General notices are Federal and State regulations contained in the bid proposal, which govern or affect the conduct of the work.

Requests for clarifications or interpretation of the contract documents must be submitted, in writing, to the agency's administrative manager within a stipulated period prior to the proposal opening date. Interpretations or explanations issued in response to such inquiries are issued as an addendum to the bid proposal and furnished to all prospective bidders in writing sufficiently in advance of the bid opening. Design changes made prior to bid opening are also issued as addenda to the contract. Design changes made afterward are issued as revisions. Bidders are typically required to provide signed affidavits indicating that they have received all addenda issued by the agency. Bids, which do not include all required documentation, including the requisite affidavits, are considered nonresponsive.

Bids for public highway work are submitted on formal bid proposal forms, either typed manually on paper forms or electronically with a hard copy generated from the electronic file. The bidders specify a unit price in numerical figures for each contract line item in one column and in words in another column. Bidders complete the cost extension for each line item and show the product of the quoted unit price and quantities in numerical figures in the column provided. The total bid amount is obtained by adding the extensions of the individual line items. It is usually required that the figures and words are typewritten. Some agencies will accept handwritten substitutions of the typewritten unit prices on the bid form, provided the typewritten amount is crossed out with a single line, the substitution is legible and written in ink, and the change initialed by the bidder authorizing the substitution.

Bids are placed in a sealed envelope and clearly labeled to indicate the contents. The information also includes the contract designation and the name and address of the bidder. Bid proposals are then delivered prior to the time specified to the place indicated in the advertisement. Any bid proposals received after the specified time are returned to the bidder unopened. Typically, this is a hard and fast rule with no exception. Bidders bear the risk of delivery and therefore will often choose to have their own personnel make delivery. Another reason that this is often necessary is that bidders are frequently assembling their bid packages right up until the last minute. Assembling bid proposals requires consideration of price quotations submitted to the bidding contractor by prospective subcontractors and suppliers. Subcontractor and supplier quotes are often not received until the morning of the bid opening.

Bids are opened and read publicly at the place and time designated in the advertisement. In addition to the bid form, the bid package must include various other documents including non-collusive bidding certification, proposal guaranty, good faith effort documentation for DBE requirements, and any signed affidavits listed in the proposal. Proposal guaranty can be in the form of a certified check, cashier's check, treasurer's check, or other negotiable/transferable instrument in the sum equal to at least 10% of the bid. A bid bond may also issued by a third-party surety is also acceptable proposal guaranty. After the proposals are opened and read, the agency compares proposals on the basis of the summarized cost extensions which for the bid prices. The agency reviews the apparent low bid to confirm that it is responsive in every aspect. If so, the contract is awarded to the low bid. If not, the next lowest bid is reviewed for responsiveness and if confirmed, the second place bidder is awarded the contract.

Formal award of the contract is made in writing to the successful bidder. The Notice of Award is generally made within as specified time frame, usually 30 days after the bid opening. The time between the bid opening and the award can be extended when agreeable to both parties. Most public agencies reserve the right to cancel the award of the contract before execution without liability. 03.05 The successful bidder must present the owner with performance and payment when executing the Contract. The bond amounts must equal 100% of the contract price value. The successful low bidder signs and returns the contract and bond(s) to the owner within a specified period, usually 15-20 days after the Notice of Award (NOA). Once the owner receives the executed documentation, a Notice to Proceed (NTP) is issued to the contractor. The NTP is a written notice to the contractor to begin construction. The NTP usually releases the contractor to begin construction immediately but often contains a window in which work

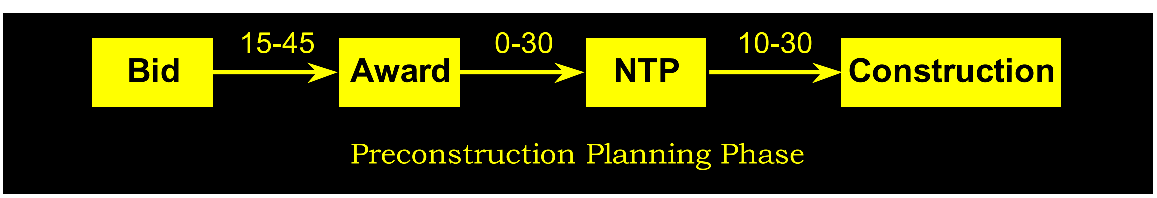

Figure 50 - Time Frame from Bid Opening to the Start of Construction

may start. A typical NTP window might include 10 days. Time charges begin when the work starts or at Day 10, whichever occurs first. That first chargeable working day (WD) serves as a milestone that signals the completion of the procurement phase and the beginning of the construction. The end of the construction phase can be considered to occur at substantial completion, the last chargeable WD, or final acceptance of the work by the owner.

4.3.3. Design-Build

Design-Build (D-B) is a project delivery system used to deliver a project in which the design and construction services are contracted to a single entity. The single entity is

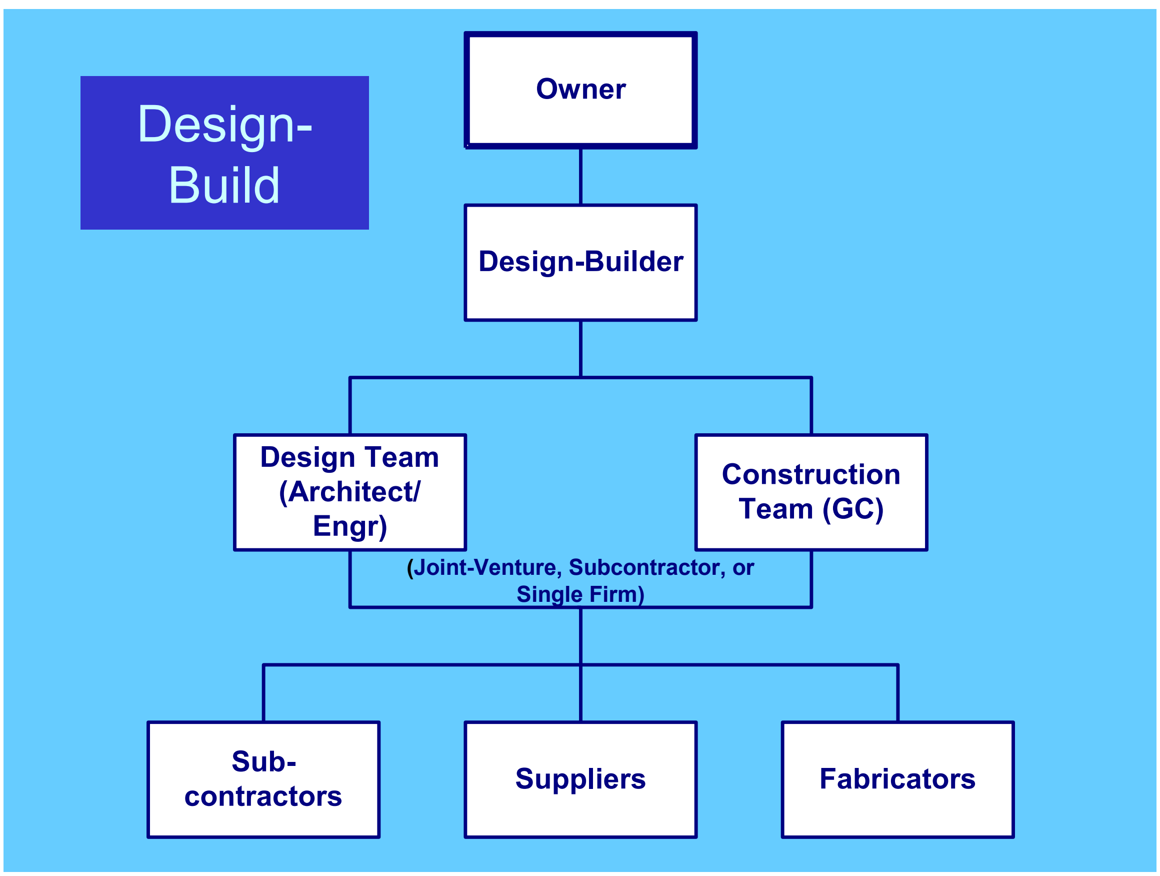

Figure 51 - Organization Chart for Design-Build Project Delivery

referred to as the design-builder. Design-build is based on a single point of responsibility with a single contract covering both design and construction. The design-builder can be a contractor-lead team that includes a design consultant in a subordinate position or a single integrated organization with in-house design capabilities. The latter must hold the necessary engineering licensure and be prequalified to perform design services. Design-build contracting in the private sector does allow joint ventures between contractors or construction managers and design consultants. The American Institute of Architects (AIA) not surprisingly advocates having the architect in the lead role. Such an arrangement is not possible for public highway projects, mainly due to bonding requirements and limited financial capacity. Consulting engineers do not have the ability to secure the performance and payment bonds required by public highway agencies. Small and mid-size consulting firms do not possess the financial resources required to bear the overdraft that is routinely financed by general contractors and construction managers at-risk

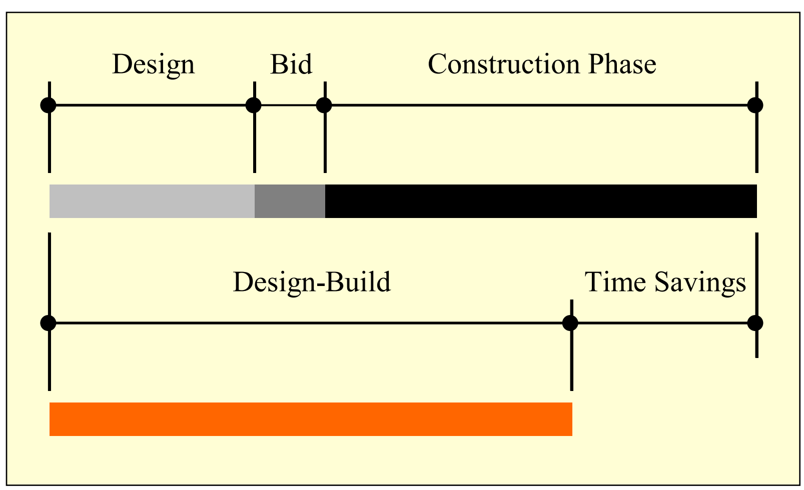

Figure 52 - Comparison of D-B and DBB Timelines

Design-build is thought to minimize risks for the owner and reduce the overall delivery schedule. Eliminating the bid phase between design and construction and employing fast-track methodology accomplish the latter. Fast-tracking is the overlapping of the design phase with construction phase. In other words, construction is allowed to begin before the design is 100% complete. Design-build delivery is common in commercial building and other AEC industry sectors. It is also fairly common in various segments of the public sector. While design-build is gaining acceptance in the highway industry, it is still considered an innovative delivery method (Muir et al, 2008). Design-build is touted as creating more efficient designs with the interjection of constructability and innovation. Reasons that public owners select D-B delivery include shorter project duration, ability to establish cost up front, potential to reduce cost, enhanced constructability and innovation, establish a schedule, reduce claims, and more efficient administration of large, complex projects ((Songer and Molenaar 1996). Disadvantages include the complexity of evaluating proposals.

Design-build success criteria are very close to the definitions of success in general construction (Molenaar et al 1999; Chan et al 2002). Design-build success criteria include time, cost, and conformance to owner expectations, administrative burden, and overall user satisfaction. Safety, team satisfaction, and reduction in disputes can be added to the list (Chan et al 2002). Time and cost in terms of schedule variance and budget variance respectively are the strongest criteria. Certain variables referred to as project characteristics affect success (Songer and Molenaar 1997). Project characteristics related to design-build include a well-defined scope, shared understanding of scope, owner's construction sophistication, adequate owner staff, and established budget. Other characteristics include owner's risk aversion, owner's willingness to forego design input, selection process, design-build process variability, and others. Some agencies such as

Florida DOT have significant experience and expertise in administering D-B projects and exhibit these positive characteristics (Muir et al 2008). The various public highway agencies that employ D-B do so under their State's procurement laws. The selection process is critical to success in D-B. However, some state's procurement laws prohibit anything but sealed low bid selection. Florida's laws were changed to allow a two-step process that is a best-value selection variant. Research shows that there is a correlation between the method of design-builder selection and its affect on performance (Molenaar et al 1999; Molenaar and Gransberg, 2001). Design-builders selected through the two-step method tend to perform better in terms of cost, schedule, increased constructability, and reduced claims.

4.3.3.1. Fast-Track and Phased Construction

The term "fast-track" is misused and misunderstood. Some incorrectly use the term to indicate acceleration or crashing. As noted under the design-build discussion, to "fast-track" a project is to begin construction before the design is 100% complete. Fast-track construction is well suited to design-build, especially since the constructor bears the risk of design errors and omissions. Obviously, fast-tracking is not without risk, but the risk to the owner is reduced through the single point responsibility feature of design-build. There are however instances in the highway industry beyond design-build in which fast-track or in this case, "phased construction" are plausible. These tend to be large projects in which there is relatively low risk associated with performing early stage work before completing design of the finish elements.

Another contracting arrangement in AEC is the use of multiple primes or "multiprime". Multi-prime contracting is often employed with fast-track construction. In this case, the owner contracts with multiple parties responsible for the completion of various portions of the work. Multi-prime contracting sometimes referred to as "parallel prime contracting," differs from the traditional method of construction by replacing the general contractor with multiple prime contractors.

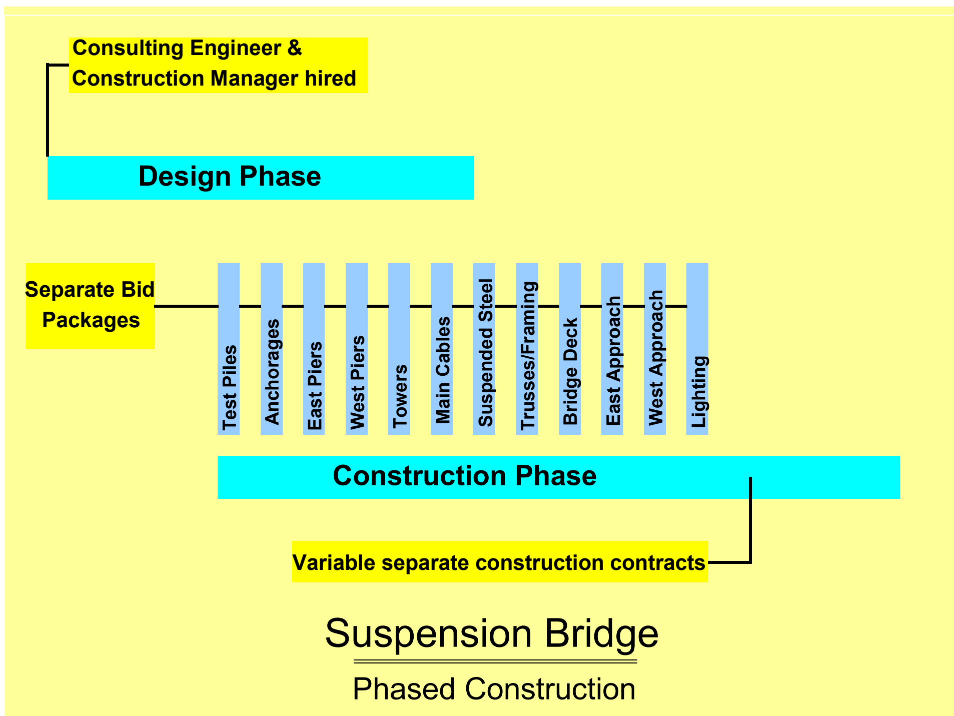

Figure 53 - Example of Phased Construction using fast-track and multiple prime construction contracts

Multi-prime contracting is an arrangement in which the Owner contracts directly with a number of specialty or trade contractors who would normally be the first-tier subcontractors in the traditional hierarchy. While there are clearly benefits that can be realized by the use of multi-prime contracting, the most significant risk is the coordination problem that multi-prime contracting can create. Coordination risks can be mitigated by the Agency Construction Management (Agency CM). Phased construction in the highway industry is different from the commercial construction form of multi-prime contracting. Phased construction also uses multiple prime contracts, but not necessarily in parallel. There may be some overlap of contracts, but not the same congruence as in multi-prime commercial construction. Figure 53 shows a suspension bridge project in which phased construction is employed.

4.3.4. CM At-Risk and Agency CM

The terms "construction management" and "construction manager" have multiple meanings and connotations depending on context. Construction management can mean the application of engineering and business principles to construction operations; both in the field and office. It can be further extended to include construction company management. A construction manager can be one that manages construction operations. It can also refer to a specific job title or position within an organization. The terms construction management and construction manager also have specific meanings in project delivery. Construction management can be a project delivery system or management system defined by a contractual arrangement. The construction manager (CM) has considerably usurped the role of the general contractor (GC) in commercial building construction. Many of the older GCs in commercial work have morphed into CMs. CM At-Risk is both the name of a delivery system and the contracting party. CM At-Risk assumes the role of the prime contractor, responsible for all cost and performance risks associated with the contract. As with owner-GC arrangement, all risks of performing the work are transferred to the CM. However, the CM does not self-perform any of the work. What the CM does provide is coordination and oversight. The CM does not carry any direct labor on its payroll; only management personnel. The CM possesses the financial resources, knowledge, and bonding necessary to undertake a construction project. But unlike the GC, the CM has no labor or equipment resources and must rely on specialty subcontractors to physically execute the work. The CM typically offers diverse expertise in design, construction, and management not usually associated with general contracting.

CM At-Risk delivery enables the owner to procure a CM prior to completion of the design phase. Procurement is typically qualifications-based. The CM can work with the designer to help ensure constructability, advise on costs, and confirm the schedule. CM At-Risk delivery method also enables fast-tracking, thereby expediting the construction phase and reducing the overall project duration. Pricing is typically GMP. CM At-Risk is thought to save the owner time and money and reduce claims through early access and input in the design. It is expected to reduce design errors and omissions, change orders, and warranty issues. It is also believed to enhance transparency and eliminate post-award bid shopping[75].

CM At-Risk has been considered for use in the transportation arena. It was initially introduced to the highway industry in the U.S. by the FHWA through SEP

[75] "Bid Shopping" refers to actions taken by the prime contractor to reduce subcontractor prices by "shopping" the lowest bid in a particular craft from subcontractor to subcontractor. This practice is considered highly unethical and illegal in some public work. Post-award bid shopping does not add value to the owner and is injurious to the specially contracting community.

(Special Experimental Project) 14[76]. Traditionally, highway construction contracts typically require that the GC acting as prime contractor self-performs at least 50% of the actual construction work. According to the FHWA, CM At-Risk demonstrates certain advantages over traditional low-bid general contracting procurement. The FHWA views the fact that the CM At-Risk can provide advisory professional management assistance during preconstruction is valuable for certain types of projects. The CM has the latitude to recommend and implement design changes, provided a benefit is recognized (FHWA http://www.fhwa.dot.gov/programadmin/contracts/sep14dt.cfm 8/31/11 at 2:00 PM EDT). Activities such as utility relocation can begin prior to 100% completion of design drawings translating into an early project completion date. The FHWA views the disadvantages of tradition low-bid procurement in that it "discourages or precludes innovation in design and construction or installation methods. It does not allow the owner to consider any factors other than price in selecting the contractor (except at a fairly low responsibility pre qualification level). The contractor is likely to feel they left too much money on the table and may try to cut costs during design and construction, adversely affecting quality, and, it does not permit a meaningful dialogue between the owner and the individual bidders to work out the appropriate solution to the transportation agency's needs."

The FHWA is proposing a variant of CM At-Risk referred to as CMGC through its "Every Day Counts" (EDC) innovation initiative. Construction Manager General (CMGC) is similar but different from CM At-Risk that is routinely employed in

[76] Special Experimental Projects No. 14 - Alternative Contracting, formerly Innovative Contracting, is an FHWA program that has allowed the State DOTs to evaluate non-traditional contracting techniques since 1990 and continues today in that mission.

commercial building or “vertical” construction. CMGC considers the unique aspects of transportation industry projects, including self-performance requirements and the prohibited engagement of subcontractors below the first tier. CM At-Risk procurement use qualifications-based selection with GMP pricing. CMGC uses best-value selection. The FHWA cites the following advantages of CMGC over traditional low-bid procurement: constructability of designs, timely cost information, cost certainty, better/faster schedules, owner input into design decisions (sacrificed in DB), and team atmosphere conducive to timely conflict resolution and claims avoidance.

The CMGC system requires a separate contract between the owner and a designer. CMGC is a two-phase contract with a general contractor. Phase I – “Construction Management” is a consulting contract to assist in the design process, followed by Phase II - “General Contracting” contract to build the project.

Agency CM is a management system, not a delivery system in which the CM acts solely as the owner’s agent. It is considered pure construction management. In this pure form, the CM takes no entrepreneurial risk for costs, timeliness, or quality of construction. Privity does not between the CM and the subcontractors. The owner directly contracts with all subcontractors. The CM provides close coordination between design and construction acting as an agent of the owner. The CM brings specialized construction skills and knowledge through all project stages including preconstruction, similar to the CM At-Risk. Ideally, the agency CM acts as the owner’s agent in supervising and coordinating all aspects of the project from the beginning of design to the end of construction. As an agent of the owner, the CM has delegated authority only. The agent is empowered by the owner and is most effective when granted decision - making power and can react quickly to resolve issues on the owner's behalf. The agency arrangement tends to eliminate the impact of conflicts of interest and unfetters the decision making process. Since the CM takes no entrepreneurial risks, it is able to provide independent and objective evaluation of costs, schedules, and performance. The value added to the owner from this independent expertise includes potential savings in time and cost. At the same time, the disadvantages include the fact that the CM theoretically shares no risks associated with costs increases or time escalation and is viewed to lack financial incentive for timely on-budget completion. However, agency CMs are procured through qualifications-based selection. Poor project performance can damage a CM's reputation and hinder future selection.

Public highway agencies have long used a variant of agency CM for project of all sizes and degrees of complexity. The service usually comes in the form of Construction Engineering and Inspection (CEI). Consultants serving in a CEI capacity are occasionally involved in preconstruction services such as constructability studies or value engineering. However, CEI services are usually limited to the construction phase.

4.3.5. Procurement Hybrids

Joint ventures are formal supply chain partnerships conceived to construct a single project. Joint ventures provide the opportunity for local or regional contractors to pool resources and take on large-scale projects. In addition to critical financial resources, joint ventures come to the table with greater combined bonding capacity, which is especially crucial for public works projects.

4.3.5.1. DBOM, DBOT, and the Rest

Innovative Delivery Methods intended to expand opportunities for owners and providers that would not be otherwise viable continue to evolve. Hybrid project delivery solutions often affect the project life cycle beyond startup. Procurement hybrids transcend design and construction and involve financing, operations, and maintenance of constructed facilities. These hybrids include build-operate (BO), build-operate-transfer (BOT), design-build-finance (DBF), design-build-operate (DBO), design-build-operate-transfer (DBOT), and design-build-operate-maintain (DBOM). Public-Private Partnerships employ one of the hybrid delivery forms.

The use of long-term hybrid delivery for infrastructure facilities is a growing trend worldwide, particularly prolific in Europe and Asia. Research results confirm success criteria. First, there must be a viable business plan with sufficient margin to weather economic downturns, inflated income or insufficient allowance for capital, operating, and maintenance expenses. Sufficient initial funding must be available as well. Innovative project delivery schemes have evolved as a means of getting these projects built. Delivery of an increasing number of public infrastructure is the result of private financing and surrogate ownership. While demand for new or reconstructed infrastructure continues to grow, the available funds continue to shrink. However, everything follows funding; real estate, design, construction, operations and maintenance. Various organizational and contractual arrangements have surfaced. Large consortiums have formed to provide owners with integrated design, construction, maintenance, and operating services. Integrated one-stop-shopping confronts owners with significant advantages and disadvantages. Generally, the most critical component is finance.

4.3.5.2. Public-Private Partnerships

Innovative delivery options include private sector investors joining with public owners in public-private partnerships (PPP or P3)[77]. In Europe, these ventures have matured through the judicious application of arrangements referred to as "concessions". The generally accepted definition of a concession is a document that “establishes a commercial agreement between the government and a private builder, owner or operator of an element of public infrastructure”. Such infrastructure includes toll roads, power plants, wastewater treatment plants, trash-to-steam stations, etc. These contracts are quite complex and comprehensive in that they must address every conceivable issue surrounding what is usually a long-term relationship. The document must be balanced in that it fully protects the public interest while attracting private investors. Some concessions are essentially joint venture agreements between the public and private partners, while others are more in the form of a commercial license to construct and operate what has traditionally been a public facility.

There are many permutations of concessions, which vary across global regions. Concessions in the U.S. have seen mixed results at best. The use of concessions in this country is really still in its infancy. While the need is great, the capacity for embracing PPP and concessions in general is limited by procurement barriers, lack of understanding, and unwillingness on the part of many public owners to embrace partnership. As previously stated, these ventures must demonstrate long-term financial viability. Both

[77] The author prefers PPP over P3 since P3 is also an abbreviation for Primavera Project Planner scheduling software. However, P3 is the nomenclature that has been adopted by the FHWA and will therefore be used in this section.

parties must share verifying and ensuring financial viability. Government partners must at once maximize attractiveness to investors while safeguarding the public interest, which is not a simple task.

Many P3 projects have failed from the investor's perspective as a direct result of the public owner's action or inaction. The incentives and contractual mechanisms must be designed to capitalize on the strengths of both the private and public sectors. From the public sector: 1) leadership in the public forum, sponsorship and championing the project, 2) navigation through the entanglement that is government regulation, 3) providing clear standards and explicit short-term and long-term expectations based on performance criteria, 4) establishing a transparent and consistent procurement process. Some would argue that the process should be based on and supported strictly by quantitative measures.

While the author believes that strong quantitative metrics are essential, they must be tempered by qualitative best-value principles, 5) cultivating a collaborative partnership and a more fully integrated supply chain, 6) fair and appropriate allocation of risk, 7) dedication to verifying technical efficacy of design proposal, while remaining flexible and willing to relinquish a certain level of control. From the private sector: 1) innovative leadership in business and program management, 2) excellence in design and construction, 3) excellence in maintenance and operation, 4) faithful dedication to the public interest, 5) seek to more accurately forecast and validate pro forma data.

The FHWA is a strong proponent of PPP for delivery of transportation infrastructure. The following is from their Innovative Program Delivery website:

"FHWA encourages the consideration of public-private partnerships (P3s) in the development of transportation improvements. Early involvement of the private sector can bring creativity, efficiency, and capital to address complex transportation problems facing State and local governments. The Office of IPD provides information and expertise in the use of different P3 approaches, and

Table 11 – P3 Options P3 Options for Transportation Infrastructure
Adapted from the FHWA Innovative Program Delivery website
http://www.fhwa.dot.gov/ipd/p3/defined/index.htm on 8/31/11

Public Responsibility — Private Responsibility

P3 Options			
New Build Facilities	Design Build	Design Build Operate (Maintain)	Design Build Finance Operate
Existing Facilities	O & M Concession		Long Term Lease
Hybrid			Lease Develop Operate

assistance in using tools including the SEP-15 program, private activity bonds (PABs), and the TIFIA Federal credit program to facilitate P3 projects[78]."

There are several diverse P3 structures. The differences include the degree to which the private sector assumes responsibility, especially the financial risk. Various types of P3s

[78] SEP-15 is a new experimental process for FHWA to identify, for trial evaluation, new public-private partnership approaches to project delivery.

are well suited to development of new infrastructure, while others are more appropriate for the operation or expansion of existing facilities. The various P3 options are shown in Table 11.

CHAPTER 5: RESEARCH FINDINGS AND ANALYSIS

5.1 Data Collection and Validation

Data collection for the HPP Study utilized the 4-page questionnaire as the sole instrument. As noted in Chapter 2 discussing research methodology, final data collection after the pilot study began in July 2010 and the last completed questionnaire was received in October 2011. The responses included twenty-five (25) paper and forty-three (43) web-based in SurveyMonkey for a total of sixty-eight (68). Review of the responses revealed that several were missing information, included contradictory information, or the accuracy was suspect. The author obtained the missing information through follow-up telephone calls to the project managers listed on the questionnaires. The listed project managers were not always able to provide the missing information. However, in most cases, those contacted were able to direct the author to the appropriate parties that could provide the missing information. These were typically resident or area engineers. In retrospect, it would have been better if the questionnaire's open-ended questions identifying the Project Manager (PM) and the PM's phone instead sought to identify the Resident Engineer (RE) and the RE's phone number.

The author was unable to complete or otherwise validate three (3) questionnaires started in SurveyMonkey. One questionnaire that was missing several pieces of information did not have the requested PM contact information and the author was not able to trace the respondent, nor identify individuals with the sufficient knowledge of the project. The project was therefore not included in the final HPP Study. The author was not able to obtain the original contract duration for a second project. The original contract duration is information that is vital to the study. Therefore, the project was dropped from the study. A third project for which a questionnaire was started in SurveyMonkey not finished. The projected completion date is 11/15/2013. The study only includes data from completed projects. This third project was also dropped from the study.

5.2 Pool of Sample Projects

As previously discussed, 10 highway agencies across 8 states participated in the survey providing a total of 68 sample projects and a final pool of 65 projects. The projects and their agencies will not be further identified within this thesis. This practice is necessary to shield identities and maintain the commitment made as promised in the closing statement on the questionnaire and other documents used to solicit participation in the study. The closing statement on the HPP Study questionnaire stated that "*The collected information shall not be used to criticize or denigrate any project, organization, or individual. Furthermore, reports of the findings shall not reveal performance of specific projects; identify individual contractors, designers, agency employees, etc.; reveal performance of individual agencies to others; single out any one project for any reason - positive or negative. For the sake of objectivity and shielding of participants, the text will not report or categorize the data by state, municipality, or agency but by engineering classifications only.*" Projects are identified by two-digit Internal Reference# only. The owners' name, project name, contract number, F.A.P. #, location, Project Manager, and PM's Phone are all omitted from the spreadsheet. Other information within the body of the data that may reveal the project or its owner will be masked accordingly. This distribution of the projects across various highway agencies will not be revealed in this thesis or in any publically available document or presentation.

5.2.1 Analysis of Distribution

The TPI values from the 65 projects in the final pool were further analyzed, beginning with the descriptive statistics. The data were then tested for normality, that is, whether the data are normally distributed or belong to another distribution. Normality is an important assumption for many processes in inferential statistics and this thesis. Minitab 16 was used to conduct the Anderson-Darling Test for Normality on the TPI values from the final pool of projects. The Minitab output from that test is shown in Figure 54.

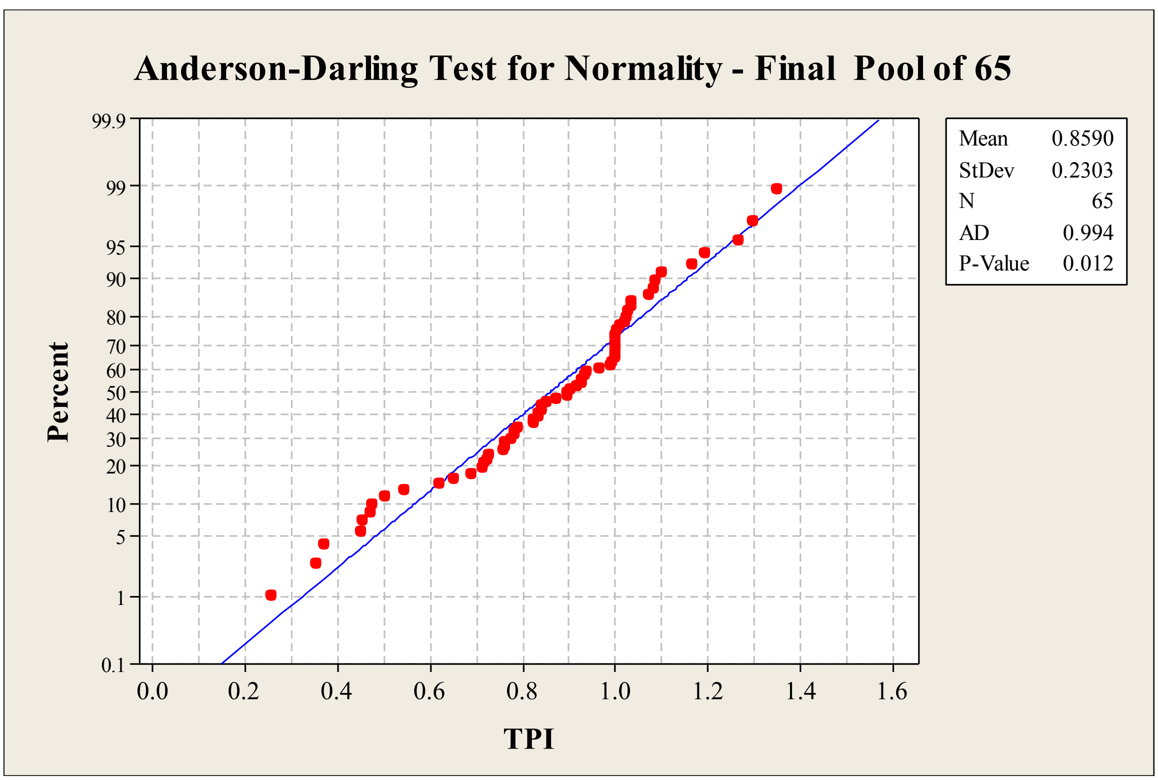

Figure 54 - Probability plot of TPI for final pool of projects

Note from the graph that a plot of the continuous variable, TPI, appears close to but is not quite normally distributed. The Mean is 0.859 with a standard deviation of 0.230 and Anderson-Darling Test Statistic (AD) of 0.994 for n = 65. The most telling indicator is the p-value,. which is 0.012. The null hypothesis for the normality test is that the distribution of the data does not differ significantly from a normal distribution. Obtaining a p-value greater than 0.05 indicates that the data are most likely normally distributed. Conversely, a very small ($p<0.05$) p-value indicates that it is not likely that the data are normally distributed. Since the p-value is less than 0.05, the clear decision is to reject the null hypothesis. It was understood that the data was not likely from a normal distribution. Therefore, the analysis that follows is based on non-parametric testing.

Table 12 - Descriptive Statistics for TPI

Descriptive Statistics for TPI			
Descriptive Statistic	**Final Pool**		
	All Projects	**On Time**	**Late**
Mean TPI	0.859	1.080	0.746
Standard Error	0.029	0.023	0.029
Median	0.896	1.030	0.782
Mode	1.000	1.000	0.831
Standard Deviation	0.230	0.106	0.191
Sample Variance	0.053	0.011	0.037
Kurtosis	0.223	1.056	-0.043
Skewness	-0.534	1.454	-0.885
Range	1.091	0.348	0.741
Minimum	0.256	1.000	0.256
Maximum	1.348	1.348	0.998
Sum	55.834	23.752	32.082
Count	65	22	43
Confidence Level (95.0%)	0.057	0.047	0.059

Table 12 presents a display of the descriptive statistics for the final pool of projects. In addition to the pool of All projects, the analyses include the subsets of On Time and Late projects.

5.2.2 Disproportional Contributions

Two agencies in the study represent large sectors of the project pool. One agency represents 29.2% of the pool and a second accounts for 23.1%. Together, they account for over half of the projects in the final pool. It was therefore necessary to confirm whether the Mean TPI values of the projects from these two agencies were the same as those from the other 8 agencies combined. This step was vital to assure that the large contributions by these two agencies were not introducing bias or otherwise skewing the data with respect to the TPI. Analysis for this step initially included the Kruskal-Wallis test. These two agency groups and a third that represent the other agencies were given the pseudonyms Lions, Tigers, and Bears. Table 13 shows the Minitab output for the Kruskal-Wallis test of TPI values for these three agency groups.

Table 13 - Kruskal-Wallis Test: TPI versus Agency Group

Kruskal-Wallis Test on TPI

Agency Group	N	Median	Rank	Z
Lions	31	0.9977	38.9	2.39
Tigers	19	0.8415	30.3	-0.75
Bears	15	0.7732	24.3	-2.02
Overall	65		33.0	

H = 6.54 DF = 2 P = 0.038
H = 6.54 DF = 2 P = 0.038 (adjusted for ties)

The Kruskal-Wallis test is a non-parametric, multiple comparisons used to determine whether differences occur between the medians of more than two samples. The test does not require normality or equal sample size, provided there are more than 5 observations per sample. The null hypothesis is H_0: $M_1 = M_2 = M_3$. The alternative hypothesis is H_1: Not all M_j are equal. The null hypothesis is rejected if the test statistic H is greater than the χ^2_{CRIT} for c – 1 degrees of freedom at a given level of significance, α, or if the p-value of the test is less than α. The test statistic H of 6.54 is greater than χ^2_{CRIT} 5.991 for $\alpha = 0.05$ at 2 *df*. Also, the p-value = 0.038 is less than 0.05. Therefore, H_0 is rejected. The next step in the analysis was to determine where the differences occurred. The Mann-Whitney test was applied for that purpose.

Mann-Whitney test is the non-parametric equivalent of the independent samples t-Test[79]. The Mann-Whitney test is potentially three to four times greater power than the t-Test (Devore 2008). The test's objective is to identify differences between the distributions of the two samples. The null hypothesis is that there is no significant difference between the sample median TPI values between project groups. The differences are significant if p is smaller than $\alpha = 0.05$. Table 14 displays the Minitab output for the Mann-Whitney tests conducted on the three data sets. The resulting p-value for Lions vs. Tigers was 0.1009 and 0.2980 for the Tigers vs. Bears. Since both p-values are greater than $\alpha = 0.05$, H_0 is not rejected for these pairings. However, the p-value for the Lions vs. Bears is 0.0203 which less than $\alpha = 0.05$. Therefore, the results are significant and the null hypothesis is rejected for this pair, meaning that there is a significant difference between the Lion and Bear agency groups.

[79] The Mann-Whitney test is also known as the Wilcoxon rank-sum test (Devore 2008)

Table 14 – Minitab Output of Mann-Whitney tests of the various project subsets

Mann-Whitney Test and CI: Lions, Tigers

	N	Median
Lions	31	0.9977
Tigers	19	0.8415

Point estimate for ETA1-ETA2 is 0.1017
95.2 Percent CI for ETA1-ETA2 is (-0.0048,0.2109)
W = 873.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.1012
The test is significant at 0.1009 (adjusted for ties)

Mann-Whitney Test and CI: Tigers, Bears

	N	Median
Tigers	19	0.8415
Bears	15	0.7732

Point estimate for ETA1-ETA2 is 0.0715
95.2 Percent CI for ETA1-ETA2 is (-0.0615,0.2134)
W = 363.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.2981
The test is significant at 0.2980 (adjusted for ties)

Mann-Whitney Test and CI: Lions, Bears

	N	Median
Lions	31	0.9977
Bears	15	0.7732

Point estimate for ETA1-ETA2 is 0.1731
95.1 Percent CI for ETA1-ETA2 is (0.0383,0.3121)
W = 828.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0204
The test is significant at 0.0203 (adjusted for ties)

Since there is no significant difference between the Lion and Tiger agency groups, these two are combined in the analyses and report of findings trough the balance of this thesis. The combination of these two groups is labeled under the "Liger pseudonym[80]

5.3 Data Organization Process

Workbooks in Microsoft Excel were used to organize, sort, and initially analyze the data. Columns were assigned to each of the data categories with projects placed in the rows. Initially, the order of the columns followed the order of the questions on the questionnaire. Columns were rearranged in later versions of the spreadsheet to facilitate analysis. Additional columns were also inserted to better summarize and group the data and begin the analysis process. The process of entering the data required two different procedures due to the fact that data were collected through two distinct mediums; paper and web-based questionnaires. The paper questionnaires required manual entry of all the data into the Excel workbooks. Responses were downloaded into the Excel format. Downloads from SurveyMonkey required some manipulation prior transferring into the HPP Study workbook. Entry of the data from the questionnaires completed in SurveyMonkey was much less laborious. While more laborious, the manual process naturally provided some initial validation that was missing with electronic transfer. Of course, both manual and electronic methods have certain strengths and weaknesses, and required diligent quality control to avoid introducing additional error. Minor adjustments included sorting and formatting the Excel output from SurveyMonkey. Once the minor

[80] A liger is a hybrid feline cross between a male lion and a tigress and are found only in captivity

adjustments were complete, the data were merely copied and pasted into the HPP Study spreadsheet. The spreadsheet included a column to identify whether the projects were entered from the paper questionnaire or from SurveyMonkey

Once the data were entered into the spreadsheet for the final pool of 65 projects, additional columns were inserted to facilitate sorting into “on time” (which includes early finishers), “late”, “on or under budget”, and “over budget” spreadsheets. Additional columns included those for Δt, ΔTime%, TPI, Δ$, ΔCost%, PPI, and ΔActual Cost vs. 2^{nd} Place bid as % of Actual Cost. The values for these were then computed for each project. The projects were first sorted and grouped by time. Those projects with a TPI greater than or equal to 1.0 were copied and placed in a new spreadsheet titled “On time”. Those projects with a TPI less than 1.0 were copied and placed in another new spreadsheet titled “Late”. Projects with a PPI equal to or greater than 1.0 were copied and placed in a spreadsheet titled “On or under budget” and those with PPI values less than 1.0 were placed in the “Over budget” spreadsheet.

This process revealed that of the 65 projects in the final pool, 43 or 66.15% were finished beyond their original contract duration. Similarly, 41 of the 65 projects exceed the original bid price. This translates into 63.1% of the projects finish over budget. However, the magnitude of the time escalation observed was significantly greater than the cost overruns. This observation is based on comparing the Mean TPI vs. the Mean PPI. The Mean TPI was 0.859, while the Mean PPI was 0.956. This translates into the average time escalation being 16.4% compared to 4.6% for post-award cost growth.

Several spreadsheets were added to the primary workbook. The additional spreadsheets were required to facilitate the testing that followed. These spreadsheets included the addition of summary blocks that computed the interval half width and the lower and upper limits for the 95% confidence interval (CI). The interval half width was calculated in Excel by multiplying the Mean by the t value for each TPI value. The Excel formula used to obtain t was =TINV(probability,*df*) where the probability was 1-.95 for a 95% confidence level and *df* = n-1.

5.4 Time Performance Index (TPI)

Of all the key performance indicators (KPIs) considered in this study, TPI is by far the most significant. At a glance, the TPI not only reveals whether a project was completed on time, late or early, but provides some sense of the magnitude in which the final contract duration deviated from the original contract duration. With timely delivery of service being the theme of this study, the TPI is the outcome variable of greatest concern. Time variance (TV or Δt) is expressed in days. It reflects only deviation of the actual final duration vs. the original contract duration. TV is a significant performance indicator and certainly important to those citizens impacted by the deviation. However, it fails to indicate time performance in the larger context of the project. For example, a TV of -20 days is likely to be more impactive on a project with original contract duration of 100 days than it would be for a project having 350-day original contract duration. Twenty (20) days represents 20% of the 100-day contract (TPI = .833) while 20 days is 5.7% of the 350-day contract (TPI = 0.946)

Time variance as a percentage of the original contract duration ($\Delta_{TIME}\%$) does of course quantify the deviation in terms of the larger context. A major shortcoming of both TV and $\Delta_{TIME}\%$ is that some condition must be a negative value. The typical convention is that a negative TV indicates time escalation just as it does for a negative SV in Earned

Value Analysis[81]. Recall from earlier discussions in this thesis that TV = original contract duration (OCD) – final contract duration (FCD). Obviously, if the FCD exceeds the OCD, the value of the TV will be negative. The danger here is that some may misconstrue the negative value as completing the contract early, when in fact the opposite is true. The TPI is always a positive value, where 1.0 is on time completion, values less than 1.0 indicate late completion beyond the OCD, and the values greater than 1.0 indicate early completion where the FCD is less than the OCD. The fact that the TPI is always positive and is framed within the context of full project duration makes it a KPI of high utility.

The TPI serves as primary dependent outcome variable of interest in this study and is therefore compared against the input variables of conditions, practices and constraints as well as the categorical data. In the analyses that follow in this chapter, TPI values for individual projects are compared against the project's input variables, but more frequently presented on a summary level. More specifically, the Means of input variables are compared against the TPI for on time projects, late projects, and for all projects. Table 7 lists the descriptive statistics for TPI.

As the table indicates, the Mean TPI for all projects in the final pool of the HPP Study is 0.859 with a standard deviation of 0.230. The Mean is relatively close (0.037 less) to the Median of 0.896. The Range is 1.091 with a minimum value of 0.256 and maximum of 1.348. On time projects also include those that were finished earlier than their OCD. Of the 65 projects, 22 or 33.85% were delivered on time. The Mean TPI for on time projects was 1.080 with a standard deviation of 0.106 and Median of 1.030. The

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[81] As stated previously in this thesis, the Schedule Variance (SV) equals the Earned Value (EV) – Planned Value (PV).

Mean TPI for the 43 projects or 66.15%, which had a FCD greater than their OCD was 0.746. Figure 55 shows the smoothed distribution from the histogram for the TPI of the final pool along with the subsets of On Time and Late projects.

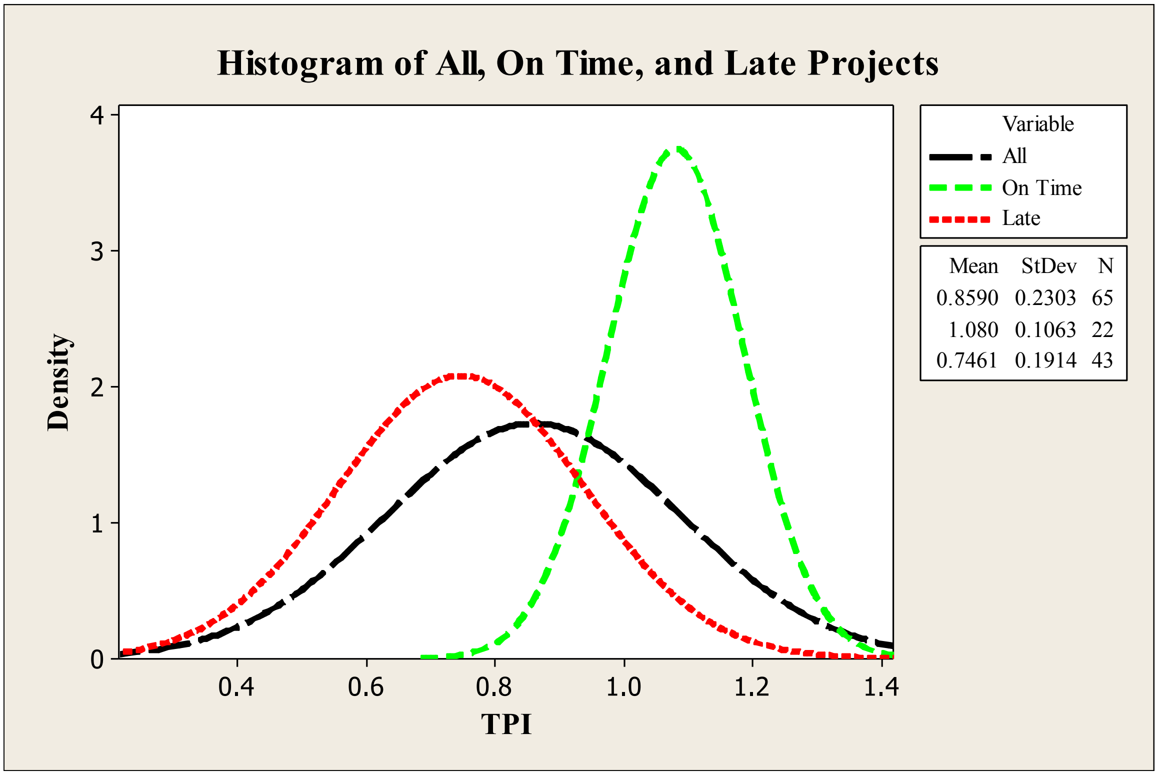


Figure 55 - Minitab output displaying smoothed histograms of TPI values for all, on time, and late projects

Comparison of the TPI Means of the On Time and Late projects was necessary in order to assume statistical significance of the analyses that follows. Since the normality assumption is not satisfied, a non-parametric alternative to the t-Test was applied in an effort to assure greater statistical power, namely the Mann-Whitney test. The null hypothesis is that there is no significant difference between the sample median of projects with a TPI greater than or equal to 1 and those with a TPI less than 1. The differences are significant if p is smaller than $\alpha = 0.05$. Table 15 displays the Minitab output for the Mann-Whitney test conducted on the two data sets. The resulting p-value is less than 0.0000 which is less than $\alpha = 0.05$. Therefore, the results are significant and the null hypothesis is rejected.

Table 15 - Minitab output of Mann-Whitney non-parametric test

Mann-Whitney Test and CI: On Time, Late

	N	Median
On Time	22	1.0295
Late	43	0.7824

Point estimate for ETA1-ETA2 is 0.2844
95.0 Percent CI for ETA1-ETA2 is (0.2192, 0.3815)
W = 1199.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

The conclusion therefore is that the subset of projects with a TPI less than 1 is significantly different from the set of projects with a TPI greater than or equal to 1. It is therefore logical and appropriate to compare these sets and their means against the different input variables considered in this study.

5.5 Survey Results

The HPP Study survey results were summarized and analyzed in essentially the same order as in Chapter 2, *Research Methodology* and presented in the sections that follow. These include categorical data, contract and performance data constraints, and practices including coordination with regulatory agencies, time management methodologies, innovative contracting methodologies or procedures, contemporary management paradigms, expediting strategies. The section next addresses project outcomes data and assessment of project inputs and outputs measured as KPIs. Each section is expanded into subsections based on the variables of interest. The results are discussed and presented in bar charts along with the corresponding contingency tables. Statistical analyses appropriate to the data type and hypotheses for each of the data sets were conducted and included in the subsections. The subsections include a discussion of the analyses and results.

5.5.1 Categorical Data

The categorical data sets corresponding with the HPP Study survey questionnaire include life cycle stage, division of work, location, functional class, project purpose, size/range: $ value, project delivery, designer, and construction management and/or inspection services. In all cases, the data were further categorized based upon performance of whether the project was delivered on time or late. Again, this category was derived based upon whether the project outcome resulted in a TPI greater than or equal to 1 for on time projects or less than 1 for late projects.

The arrangement resulted in observations that were of course mutually exclusive and collectively exhaustive, placed in two or more dimensions of classification concurrently and subsequently cross-categorized. The observations were appropriately placed in contingency tables and also arranged in other table configurations. These included tables of row percentages, tables of column percentages, tables of total percentages, and tables of joint probabilities. These tables are available in the appendix of this thesis. Each of the following subsections include bar charts with the frequency of observations plotted along y-axis with bars presenting on time, late, and the totals for each category.

The Chi-square procedure is the nonparametric test that served as the initial method of testing based upon the nature of the data and the information being sought. The Chi-square procedure is intended to test difference in the observations between combined multi-dimensioned categories. It tests the differences between two or more proportions. The null hypothesis, H_0, is that there is no difference between specified proportions. Any apparent difference would likely be the result of chance. The alternate hypothesis, H_1, is that there is a significant difference. The level of significance used was $\alpha = 0.05$. The measure of divergence is referred to as the Chi-square (χ^2) statistic. The test is significant when the calculated χ^2 is greater than Chi-square critical that occurs at $\alpha = 0.05$ at (r-1)(c-1) *df*. For the Chi-square procedure, "r" equals the number of rows and "c" is the number of columns from the table being tested. The test can also be considered significant if the p-value is less than $\alpha = 0.05$. H_0 is rejected if the test is significant. Otherwise, H_0 is not rejected and the categorical observations are not considered to be different for the given sample size.

There are two assumptions required for the appropriate application of the Chi-square procedure. The first is that the data must be arranged in independent categories. This assumption was satisfied since the categories were mutually exclusive and exhaustive. The second is in regard to the minimum expected frequency values. The specific value of the minimum frequency is subjective, with some satiations allowing as low as 0.5 up to a very conservative value of 5 (Berenson et al, 2009). While most of the expected frequency values in this study were greater than 5, the threshold was set at 1 for the procedure. The expected frequency assumption was met for all of the categories within this section, except for Project Delivery categories. The Fisher Exact Probability was applied to the Project Delivery categories, which confirmed the findings of the Chi-square test.

Table 16 - Chi-Square Test Summary

Chi-Square Test Summary - Categorical Data

Category	*r*	*c*	*df*	χ^2_{CRIT}	χ^2_{STAT}	*p*-Value	Decision	Notes
Life Cycle Stage	2	2	1	3.8415	0.0115	0.9148	Do not reject H0	
Division of Work	2	3	2	5.9915	0.9412	0.6246	Do not reject H0	
Location	2	3	2	5.9915	2.4483	0.2940	Do not reject H0	
Functional Class	2	4	3	7.8147	4.6912	0.1959	Do not reject H0	
Project Purpose	2	4	3	7.8147	3.4306	0.3299	Do not reject H0	
Size/Range: $ Value	2	4	3	7.8147	4.3852	0.2228	Do not reject H0	
Constr. Mgt/Insp.	2	3	2	5.9915	4.3526	0.1135	Do not reject H0	
Project Delivery	2	3	2	5.9915	0.0004	0.9998	Do not reject H0	(1)(2)
Designer	2	3	2	5.9915	1.8197	0.4026	Do not reject H0	(1)

Notes:

(1) A fourth column in the category was not included in the Chi-Square test procedure since it had a total value of zero.

(2) Expected frequency assumption was violated requiring application of the Fisher Exact Probability Test: 2x3. The decision is based on obtaining a *p*-value = 0.7884.

Table 16 summarizes the findings from the Chi-square test for the categorical data. The full Excel outputs for each are located in the appendix of this thesis. As noted in the summary table, the decision for each of the categories was not to reject H_0. This indicates that there appears to be no significant differences across the categories with respect to time performance. That is not to say that there are no observable differences. There does in fact appear to be differences requiring further analysis. Consequently, the

Odds Ratio (OR) and Relative Risks (RR) were computed for each category with the results presented in Table 17.

The odds ratio and the relative risk ratio are related but different measures to describe the comparative likelihood of event occurring. The odds ratio describes the strength of association or non-independence between paired binary data values. The OR is the ratio of the odds of particular event occurring in one group that is exposed to a certain condition referred to as the experimental group versus a non-exposed or "control" group. The relative risk, also referred to as the risk ratio, compares the probability of occurrence within each group rather than the odds. Relative risk is the ratio of the probability of a particular event occurring in the experimental group versus the control group. An RR of 1 indicates there is no difference in risk between the two groups. An RR of < 1 means that the event is less likely to occur in the experimental group than in the control group. Conversely, an RR of greater than 1 means the event is more likely to occur in the experimental group than in the control group.

In this study, the experimental group consists of projects within individual subcategories referred to here as factors, and the control group consists of all other projects within the category. Figure 40 shows the contingency table configuration and the equations for the OR and RR. The upper row includes the number of sample projects in which the factor was present. These are sorted across the row by whether they experienced late or on time performance. The lower row contains all projects in which the factor was not present, sorted by late then on time completion. The 95% C.I. was computed for each value of OR by adding or subtracting the product of the standard error (SE_{OR}) and Z from the natural log of the OR (ln_{OR}). A discussion of the OR and RR values and the implications for the various categories is included with each of the subsection.

Table 17 - Contingency table configuration and OR and RR statistic calculation

Contingency Table

	Performance	
Factor	Late	On Time
Present	a	b
Not Present	c	d

Calculations

OR = (ad)/(bc)

SE_{OR} = SQRT(1/a + 1/b +1/c +1/d)

95% $C.I._{OR}$ = lnOR ± (Z x SE), Z = 1.96

RR = (a/(a+c))/(b/(b+d))

Odds Ratio (OR) and Relative Risk (RR)

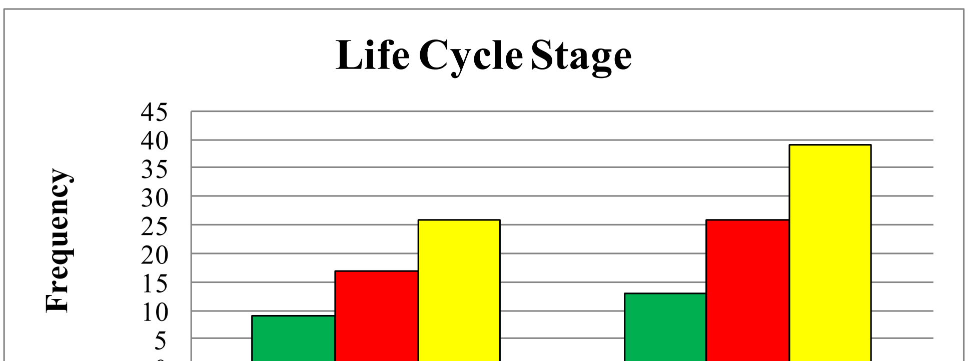
Table 18 is a summary of the OR and RR values along with the SE and 95% C.I. for the OR for each of the categories and their factors. Individual tables for the specific category are included in the subsections that follow.

Table 18 - Summary of OR and RR values for categorical factors

Odds Ratio (OR) and Relative Risk (RR)					95% C.I., Z = 1.96			
Factor	Statistic				for lnOR		for OR	
Life Cycle Stage	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
New	0.94	0.97	-0.057	0.534	-1.104	0.990	0.332	2.691
Reconstruction	1.06	1.02	0.057	0.534	-0.990	1.104	0.372	3.017
Division of Work								
Road Work	0.81	0.85	-0.213	0.600	-1.388	0.962	0.250	2.617
Roads w/Bridges	1.67	1.34	0.513	0.538	-0.541	1.568	0.582	4.796
Bridges	0.68	0.77	-0.389	0.559	-1.484	0.705	0.227	2.025
Location								
Urban	2.17	1.79	0.776	0.641	-0.481	2.033	0.618	7.638
Suburban	0.46	0.61	-0.767	0.547	-1.838	0.305	0.159	1.356
Rural	1.14	1.09	0.135	0.542	-0.927	1.197	0.396	3.310
Functional Class								
Primary Arterial	2.98	1.83	1.091	0.552	0.008	2.173	1.008	8.787
Minor Arterial	0.57	0.66	-0.567	0.592	-1.727	0.593	0.178	1.809
Collector	0.83	0.85	-0.182	0.782	-1.716	1.351	0.180	3.863
Local Road	0.35	0.41	-1.053	0.731	-2.486	0.379	0.083	1.461
Project Purpose								
Increase Capacity	1.92	1.53	0.652	0.570	-0.465	1.769	0.628	5.866
Upgrade Structure	0.43	0.51	-0.838	0.650	-2.113	0.436	0.121	1.547
Restore Function	1.43	1.28	0.357	0.576	-0.772	1.485	0.462	4.416
Safety Improvement	0.46	0.51	-0.773	0.762	-2.267	0.721	0.104	2.057
Size/Range: $ Value								
>35 Million	6.36	5.12	1.851	1.085	-0.277	3.978	0.758	53.401
>21 Million	2.41	1.92	0.880	0.639	-0.372	2.132	0.689	8.430
>5 Million	2.15	1.32	0.767	0.547	-0.305	1.838	0.737	6.286
<5 Million	0.46	0.61	-0.767	0.547	-1.838	0.305	0.159	1.356
CM/Insp Services								
Consultant	5.56	4.60	1.715	1.090	-0.421	3.852	0.656	47.079
Owner	0.41	0.56	-0.886	0.553	-1.969	0.198	0.140	1.219
Owner Lead	1.15	1.07	0.140	0.525	-0.889	1.168	0.411	3.216
Project Delivery								
DBB	0.98	1.00	-0.024	1.254	-2.482	2.433	0.084	11.397
DB	1.02	1.02	0.024	1.254	-2.433	2.482	0.088	11.960
CM At-Risk								
PPP								
Designer								
In-house	0.46	0.58	-0.770	0.580	-1.907	0.368	0.148	1.445
Consultant	2.01	1.26	0.700	0.557	-0.392	1.792	0.676	6.000
Design-Builder	1.02	1.02	0.024	1.254	-2.433	2.482	0.088	11.960

5.5.1.1 Life Cycle Stage

The Life Cycle Stage sorts projects into two categories, one for new projects and another for those that are reconstruction projects involving restoration, rehabilitation, or retrofit. Figure 56 includes the bar chart and table presenting the survey results. Of the final project pool, 26 projects or 40 % were new work, while the remaining 39 projects 60% involved reconstruction. Of those that involved new work, 9 were completed on time and 17 finished late. This represents a 35-65 split, which is essentially the same as the project. The same can be said for the restoration projects, where 13 were completed on time and 26 finished late. The fact that these splits were nearly equal is reflected in the OR and RR values, which are essentially equal to 1.



	New	Restoration/Recon/Rehab/ Retrofit
On Time	9	13
Late	17	26
Total	26	39

Figure 56 – Bar chart and table for Life Cycle Stage

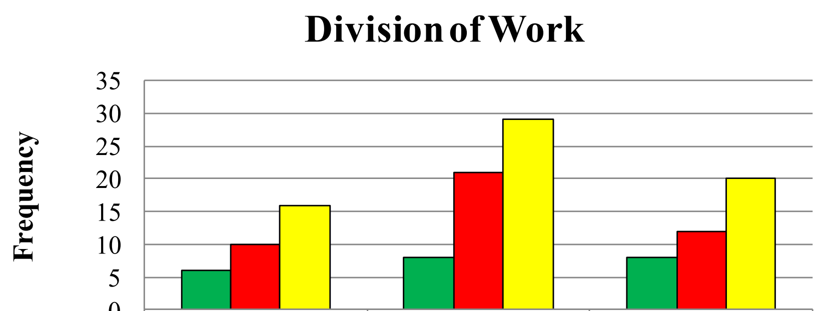
Table 19 lists the OR and RR values along with the SE and 95% C.I. for the OR for life cycle stage. The OR and RR values for new construction were 0.94 and 0.97 respectively and the values for reconstruction were 1.06 and 1.02. The Chi-square test indicated that there was no significant difference between these two proportions with $\chi^2_{STAT} = 0.0115$ being less than $\chi^2_{CRIT} = 3.8415$, with $p = 0.9148$ significantly greater than $\alpha = 0.05$ at 1 *df*. Based on these findings, it can be stated that it does not appear that projects based on life cycle stage have significant influence on performance. There is no apparent greater risk of late completion to new or reconstruction projects.

Table 19 – OR and RR Values for Life Cycle Stage

Odds Ratio (OR) and Relative Risk (RR) for Life Cycle Stage									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Life Cycle Stage	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
New	17	9	26	13	0.94	0.97	-0.05716	0.53415	-1.10410	0.98978	0.332	2.691
Reconstruction	26	13	17	9	1.06	1.02	0.05716	0.53415	-0.98978	1.10410	0.372	3.017

5.5.1.2 Division of Work

The Division of Work sorts projects into three categories, road work, road work with bridges, and bridges only. Figure 57 includes the bar chart and table presenting the survey results. Of the final project pool, 16 projects or 24.6% involved road work only, 29 or 44.6% involve roads with brides, and the remaining 20 or30.8% are include bridge work only. Of those that involved roadwork only, 6 were completed on time and 10 finished late. Eight of the projects involving roads and bridges finished on time and 21 finished late. Eight of the bridge projects finished on time and 12 finished late.



	Road Work	Road Work w/Bridges	Bridges Only
On Time	6	8	8
Late	10	21	12
Total	16	29	20

Figure 57 - Bar chart and table for Division of Work

The Chi-square test indicated that there was no significant difference between these two proportions with $\chi^2_{STAT} = 0.9412$ being less than $\chi^2_{CRIT} = 5.9915$, with p = 0.6246, greater than $\alpha = 0.05$ at 2 *df*. However, the split between on-time and late projects based on location did not match those of the final pool. Refer to the tables containing percentages aligned in various configurations available in the appendix. The frequency of late projects for those consisting of road work with bridge construction was 2.63 times greater than those delivered on time. This is in contrast to the ratio of 1.5 for the final pool.

The mean semantic differential for complexity of projects consisting of roads with bridge work was 5.250 compared to 4.250 for projects solely involving road or 4.700 for just bridge work. The mean semantic differential for complexity of the final pool was 4.828. This is a clear indication of greater complexity of projects involving road work with bridge construction.

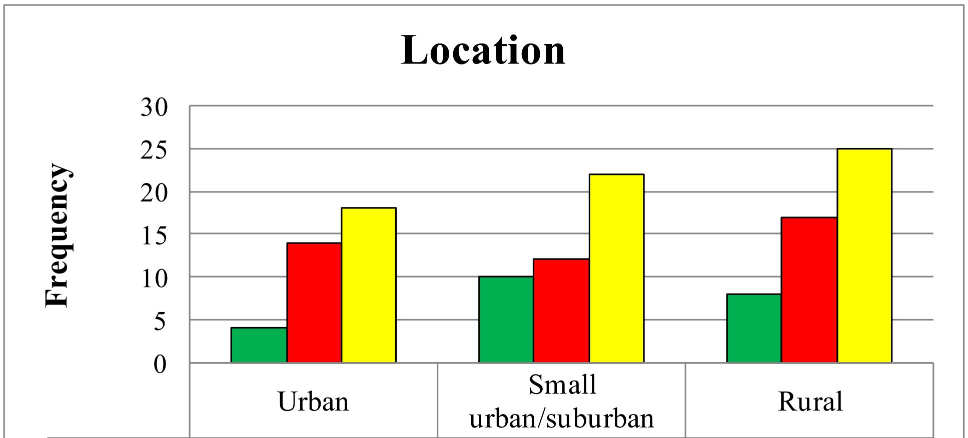
Table 20 lists the OR and RR values along with the SE and 95% C.I. for the OR for the division of work. The OR and RR for roads with bridge projects was 1.67 and 1.34, respectively. The OR and RR for roads only was 0.81 and 0.85 and 0.68 and 0.77 for bridge projects. While not substantially higher, there does appear to be a greater risk of completing projects involving both roads and bridges compared to the other divisions. The difference is something that should not go unnoticed.

Table 20 - OR and RR Values for Division of Work

Odds Ratio (OR) and Relative Risk (RR) for Division of Work									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Division of Work	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
Road Work	10	6	33	16	0.81	0.85	-0.21309	0.59956	-1.38823	0.96204	0.250	2.617
Roads w/Bridges	21	8	22	14	1.67	1.34	0.51310	0.53805	-0.54149	1.56768	0.582	4.796
Bridges	12	8	31	14	0.68	0.77	-0.38946	0.55859	-1.48430	0.70537	0.227	2.025

5.5.1.3 Location

The Location category sorts projects according to whether they were situated in urban, small urban/suburban or rural settings. Figure 58 includes the bar chart and table presenting the survey results. Of the final project pool, 18 projects or 27.69% occurred in urban location, 22 or 33.85% were suburban, and the remaining 25 or 38.46% were in rural environs. Of those that involved were urban, 4 were completed on time and 14 finished late. Ten of the suburban projects finished on time and 12 finished late. Eight of the rural projects finished on time and 17 finished late.



	Urban	Small urban/suburban	Rural
On Time	4	10	8
Late	14	12	17
Total	18	22	25

Figure 58 - Bar chart and table for Location

The split between on time and late projects based on location did not match those of the final pool. Refer to the tables containing percentages aligned in various configurations available in the appendix. The frequency of late projects located in urban settings was approximately 3.5 times greater than those delivered on time. Again, this is in contrast to the ratio of 1.95 for the final pool. The Chi-square test results include $\chi^2_{STAT} = 2.4483$ being less than $\chi^2_{CRIT} = 5.9915$, with $p = 0.2940$ greater than $\alpha = 0.05$ at 2 *df*. Chi-square testing indicated that these proportions are not significantly different; however, the disproportionate frequency of late finishers for urban projects warranted additional analysis.

The mean semantic differential for complexity of projects in urban areas was 5.500 compared to 4.565 for projects in non-urban area. This is a clear indication of greater complexity of urban projects. A comparison of constraints concluded that urban projects are more frequently exposed to utility conflicts and physical space limitations. The analysis found that 59% of projects in urban areas were exposed to utilities compared to 53% in non-urban area. The urban locations were exposed to physical space limitations on over 53% of the projects compared to 31% in non-urban area. The requirement for phased maintenance of traffic (MOT) on urban projects was 71% compared to 53% on non-urban projects. The increased frequency of these constraints on urban projects may explain to some extent their increased risk of time escalation.

Table 21 - OR and RR values for Location

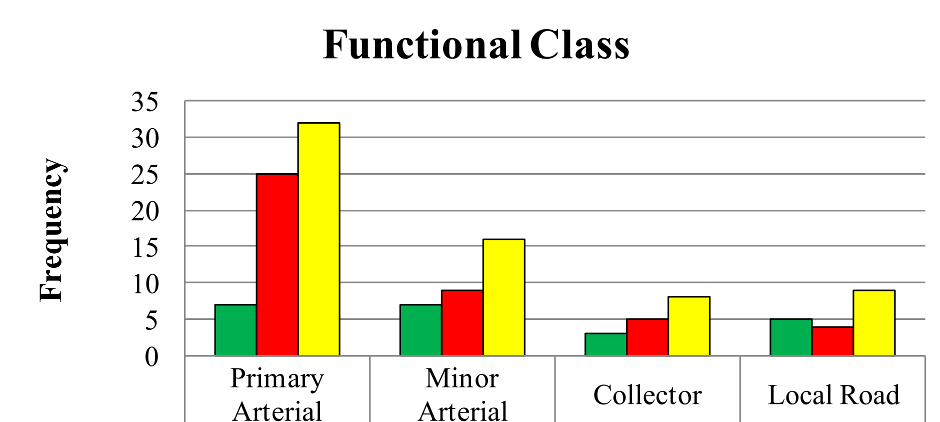
Odds Ratio (OR) and Relative Risk (RR) for Location									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Location	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
Urban	14	4	29	18	2.17	1.79	0.77584	0.64146	-0.48142	2.03309	0.618	7.638
Suburban	12	10	31	12	0.46	0.61	-0.76676	0.54674	-1.83837	0.30485	0.159	1.356
Rural	17	8	26	14	1.14	1.09	0.13473	0.54195	-0.92750	1.19696	0.396	3.310

Table 21 lists the OR and RR values along with the SE and 95% C.I. for the OR for project location. The OR and RR for urban projects was 2.17 and 1.79, respectively. The OR and RR for suburban only was 0.46 and 0.61 and 1.14 and 1.09 for rural locations. There clearly does appear to be a greater risk of completing projects in urban environments compared to the other locations. The increase in complexity and exposure to certain constraints may be factors affecting these projects.

5.5.1.4 Functional Class

Functional Classes are engineering classifications designating highway functions as primary arterial, minor arterial, collector, and local road. Figure 59 includes the bar chart and table presenting the survey results. Of the final project pool, 32 projects or 49.23%

were primary arterials, 16 or 24.61% were minor arterials, 8 or 12.31% were collector roads, and the remaining 9 or 13.85% were local roads. Of the major arterial projects, 7 were completed on time and 25 finished late. Seven (7) minor arterial projects finished on time and 9 finished late. Three (3) of the collector road projects finished on time and 5 finished late. Five (5) local road projects finished on time, and 4 finished late.



	Primary Arterial	Minor Arterial	Collector	Local Road
On Time	7	7	3	5
Late	25	9	5	4
Total	32	16	8	9

Figure 59 - Bar chart and table for Functional Class

The split between on time and late projects based on location did not match those of the final pool. Refer to the tables containing percentages available in the appendix. The ratio of late vs. on time performance for minor arterials, collectors, and local roads was lower than the 1.95 ratio for the final pool; 1.29, 1.67 and 0.80 respectively. This is reflected in the OR and RR values for these three functional classes. The OR and RR values for minor arterials are 0.57 and 0.66, for collector roads: 0.83 and 0.85, and 0.35 and 0.41 for local roads. These three classes appear to be at a lower risk of finishing late than other categorical groups. The primary arterial projects have a ratio of late vs. on time performance 3.57 times greater than those delivered on time. The Chi-square test results include $\chi^2_{STAT} = 4.6912$ being less than $\chi^2_{CRIT} = 7.8147$, with p = 0.1959, which is greater than $\alpha = 0.05$ at 3 *df.* Chi-square testing indicated that these proportions are not significantly different; however, the disproportionate frequency of late finishers for primary arterial projects warranted additional analysis.

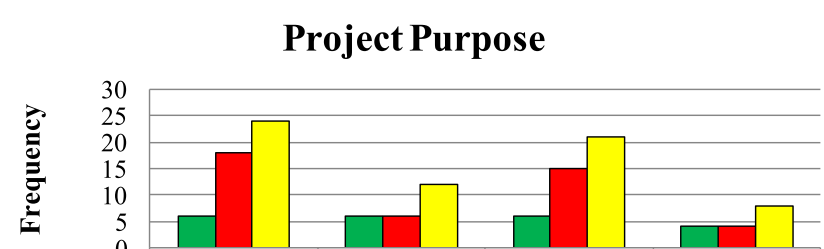
Table 22 - OR and RR values for Functional Class

Odds Ratio (OR) and Relative Risk (RR) for Functional Class									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Functional Class	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
Primary Arterial	25	7	18	15	2.98	1.83	1.09064	0.55234	0.00806	2.17323	1.008	8.787
Minor Arterial	9	7	34	15	0.57	0.66	-0.56700	0.59165	-1.72662	0.59263	0.178	1.809
Collector	5	3	38	19	0.83	0.85	-0.18232	0.78248	-1.71599	1.35135	0.180	3.863
Local Road	4	5	39	17	0.35	0.41	-1.05349	0.73107	-2.48639	0.37941	0.083	1.461

The mean semantic differential for complexity of primary arterial projects was 5.250 compared to 4.406 for projects in the other functional classifications. This difference is an indication of greater complexity in primary arterial projects. A comparison of constraints concluded that primary arterial projects are more frequently exposed to utility conflicts, streams and waterways, and wetlands. The analysis found that 61% of primary arterial projects were exposed to utilities compared to 42% for the other functional classes. Primary arterials were exposed to Steams/waterways 61% of the projects compared to 45% combined for the other classes. Primary arterials were exposed to wetlands and the accompany regulatory restrictions on 48% of the projects compared to 23% combined for the other classes The requirement for phased (MOT) on primary arterial projects was 71% compared to 45% on non-urban projects. The increased frequency of these constraints upon primary arterial projects may explain to some extent their increased risk of time escalation.

5.5.1.5 Project Purpose

Project Purpose category sorts by the primary objective or reason for the project. These include increase capacity or improve traffic flow, upgrade structural capacity, restore or maintain function, and safety improvement. Figure 60 includes the bar chart and table presenting the survey results. Of the final project pool, 24 projects or 36.92% were launched to increase capacity or improve traffic flow, 12 or 18.46% were to upgrade structural capacity, 21 or 32.31% were undertaken to restore or maintain function, and 8 or 12.31% were for safety improvements.



	Increase capacity/improve traffic flow	Upgrade structural capacity	Restoration/ maintain function	Safety improvement
On Time	6	6	6	4
Late	18	6	15	4
Total	24	12	21	8

Figure 60 - Bar chart and table for Project Purpose

Of the projects intended to increase capacity or improve traffic flow, 6 were completed on time and 18 finished late. Six (6) of the structural upgrade projects finished on time and 6 finished late. Six (6) of the restoration projects finished on time and 15 finished late. Four (4) safety improvement projects finished on time, and 4 finished late. The split between on time and late projects based on location did not match those of the final pool. Refer to the tables containing percentages available in the appendix. The ratio of late vs. on time performance for structural upgrades and safety improvements was lower than the 1.95 ratio for the final pool; 1.00 for both categories. This can be seen in the OR and RR values for these two groups. The OR and RR values for structure upgrade projects are 0.43 and 0.51, and 0.46 and 0.51 for safety improvement projects. Table 23 lists the OR and RR values along with the SE and 95% C.I. for the OR for project purpose.

Table 23 - OR and RR values for Project Purpose

Odds Ratio (OR) and Relative Risk (RR) for Project Purpose									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Project Purpose	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
Increase Capacity	18	6	25	16	1.92	1.53	0.65233	0.56984	-0.46457	1.76922	0.628	5.866
Upgrade Structure	6	6	37	16	0.43	0.51	-0.83833	0.65028	-2.11287	0.43621	0.121	1.547
Restore Function	15	6	28	16	1.43	1.28	0.35667	0.57580	-0.77190	1.48525	0.462	4.416
Safety Improvement	4	4	39	18	0.46	0.51	-0.77319	0.76236	-2.26742	0.72104	0.104	2.057

The split is higher for projects intended to increase capacity and for those undertaken to restore/maintain function. The ratio of late to on time projects for those intended to increase capacity was 3:1 and those intended to restore/maintain function was 2.5:1. The OR and RR values for projects to increase capacity were 1.92 and 1.53 and the values for those intended to restore or maintain function were 1.43 and 1.28. The Chi-square test results include $\chi^2_{STAT} = 3.4306$ being less than $\chi^2_{CRIT} = 7.8147$, with p =

0.3299, which is greater than α = 0.05 at 3 *df*. Chi-square testing indicated that these proportions are not significantly different, in spite of the relationships described above.

5.5.1.6 Size/Range: $ Value

The Size/Range: $ Value category sorted projects into 4 ranges of 2-4million, 5-20 million, 21-35 million, and >35 million. Figure 61 is a pie chart display of the ranges and corresponding percentages of the final pool and Figure 62 is a bar chart and table summarizing the survey results. The 2-4 million range included 22 projects or 33.85% of the final pool, the 5-20 million range had 24 projects or 36.92%, the 21-35 million range consisted of 8 or 12.31%, and those over 35 million in dollar value included 11 or 16.92%.

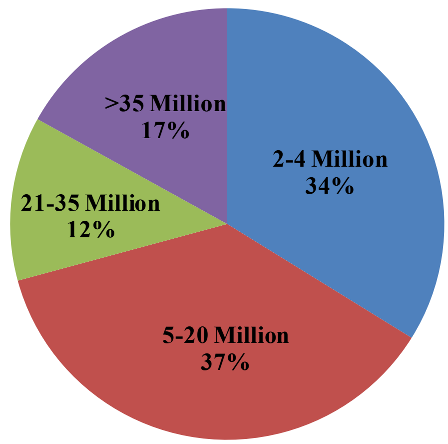


Figure 61- Pie chart of Size/Range: $ Value, %

	2-4 Million	5-20 Million	21-35 Million	> 35 Million
On Time	10	8	3	1
Late	12	16	5	10
Total	22	24	8	11

Figure 62 Bar chart and table for Size/Range: $

Of the projects valued at 2-4 million, 10 were completed on time and 12 finished late. Eight (8) of the projects in the 5-20 million range finished on time and 16 finished late. Three (3) of projects in the 21-35 million range finished on time and 5 finished late. Of the projects valued over 35 million, 1 finished on time, and 10 finished late.

The split between on time and late projects based on size/range: $ value did not match those of the final pool. Refer to the tables containing percentages available in the appendix. Projects in the 2-4 million range had a ratio of 1.2:1. Those projects in the 5-20 million and 21-35 were near the final pool ratio at 2:1 and 1.67:1, respectively. The ratio of late to on time performance for those over 35 million was lower was substantially higher than the final pool at 10:1. The Chi-square test results include $\chi^2_{STAT} = 4.3852$ being less than $\chi^2_{CRIT} = 7.8147$, with p = 0.2228, which greater than $\alpha = 0.05$ at 3 *df.* Chi-square testing indicated that these proportions are not significantly different; in spite of the substantial greater late performance of projects over 35 million. This discrepancy required closer investigation.

Table 24 lists the OR and RR values along with the SE and 95% C.I. for the OR for size/range: $ value. The OR and RR were computed differently than for the other categories to this point. The ranges were actually combined and resorted into the following ranges: >35 million, >21 million, >5million, and <5 million. OR and RR values and the related statistic were computed for each of the new ranges. The individual runs placed the factors into mutually exclusive and exhaustive groups. Figure 48 is a plot of the OR and the corresponding 95% C.I. values for each of the new ranges. The line representing the range for projects greater than 35 million is truncated at 20 for clarity, when in fact the upper limit of the C.I. is almost 54.

Table 24- OR and RR for Size/Range: $

Odds Ratio (OR) and Relative Risk (RR) for Size/Range: $ Value									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Size/Range: $ Value	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
>35 Million	10	1	33	21	6.36	5.12	1.85060	1.08532	-0.27663	3.97783	0.758	53.401
>21 Million	15	4	28	18	2.41	1.92	0.87992	0.63870	-0.37193	2.13177	0.689	8.430
>5 Million	31	12	12	10	2.15	1.32	0.76676	0.54674	-0.30485	1.83837	0.737	6.286
<5 Million	12	10	31	12	0.46	0.61	-0.76676	0.54674	-1.83837	0.30485	0.159	1.356

Interpretation of the relative risk is simpler and the understanding perhaps more intuitive and meaningful. Basically, it is the risk of an event occurring relative to exposure to a condition or other stimuli. In this case, the event is late performance and the condition is the size/range in terms of dollar value. Figure 63 is a line chart displaying the relative risk of time escalation with respect to contract dollar value.

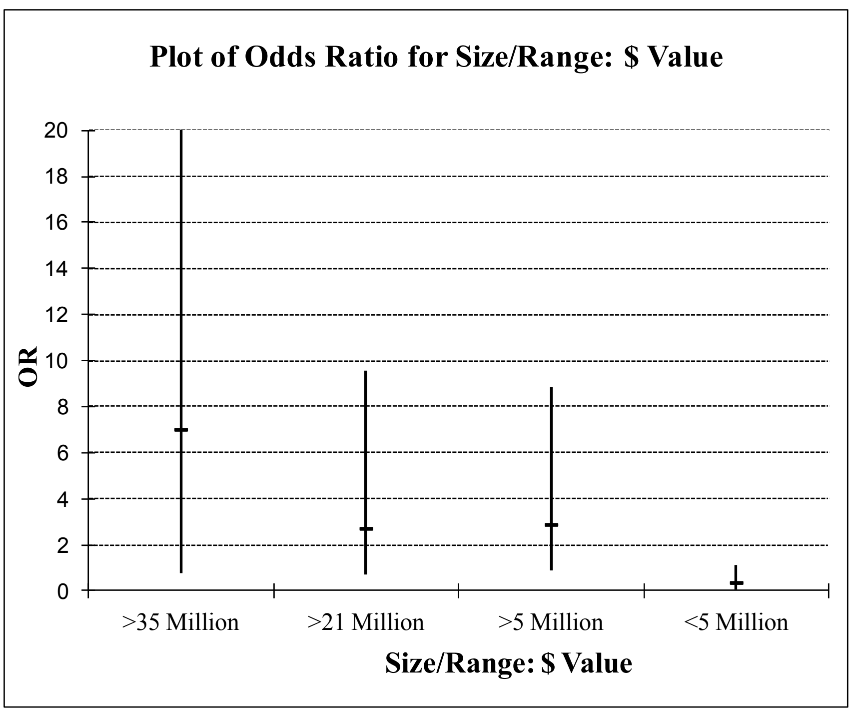


Figure 63 - Plot of OR values for Size/Range:$ with CI line

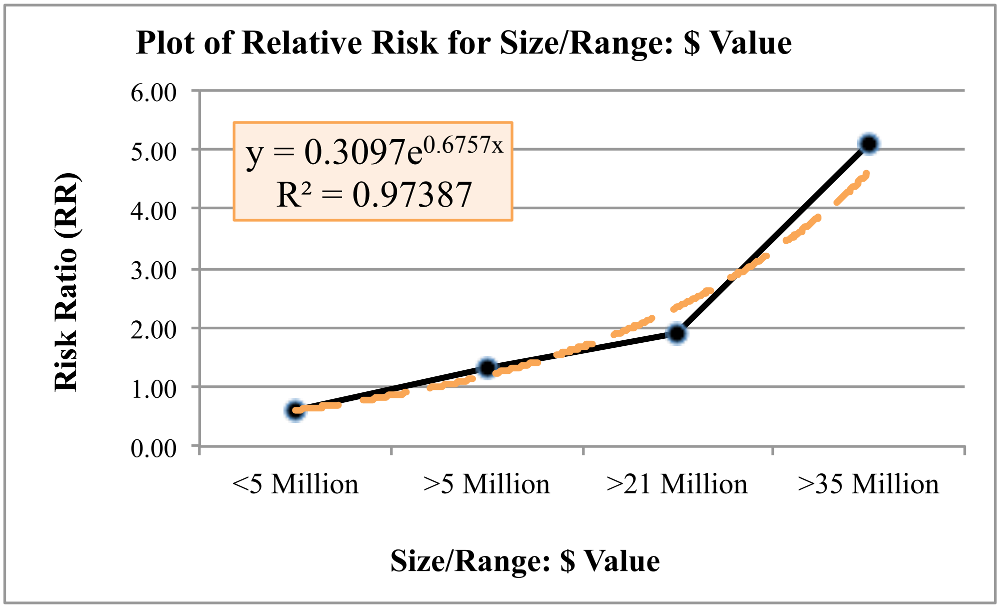


Figure 64- Plot of RR for Size/Range: $ Value with trendline

The plot shows a clear increase in the RR with a corresponding increase in dollar value. Note that the trendline placed on the plot exhibits an $R^2 = 0.97387$, indicating a strong goodness-of-fit. The best-fit trendline is an exponential curve described by the equation $y = 0.3097e^{0.6757x}$. The RR is the dependent variable y and x is a point representing the order of the size/range dollar value categories. Since x is not a continuous variable, the efficacy of this equation to forecast relative risk given a specific value is nil. While this plot is based on a limited sample size and R^2 is merely an indication of goodness-of-fit and not a metric of strength of prediction, the resulting graphic may be sufficiently accurate for highway agencies to estimate the level of relative risk of time escalation[82].

5.5.1.7 Project Delivery

The survey questionnaire directed respondents to indicate the applicable method of project delivery from a list of 4 methods. The choices included design-bid-build (DBB), design-build (DB), construction manager at-risk (CM@Risk), or public-private partnerships (PPP). Some survey responses indicated application of PPP. The validation process revealed that none of these projects were actually delivered or utilized the PPP delivery or procurement. No respondents selected CM@Risk. The overwhelming majority of projects were delivered via the traditional DBB.

Of the 62 total DBB projects, 21 were completed on time and 41 were finished late. The ratio between on time and late projects is essentially the same as the final pool, which is what would be expected given the 62 of 65 or 95% of the final pool, is in this category. DB was employed on 3 projects; 1 finished on time and 2 finished late. The Chi-square test results include $\chi^2_{STAT} = 0.0004$ being less than $\chi^2_{CRIT} = 5.9915$, with $p = 0.9998$ significantly greater than $\alpha = 0.05$ at 2 *df.* Chi-square testing indicated that these proportions are not significantly different; regardless of disproportionate amount of projects delivered thorough the traditional DDB method. Figure 65 includes the bar chart and table presenting the survey results and Table 25 lists the OR and RR values along with the SE and 95% C.I. for the OR for project delivery.

[82] Recall that n=65 for the final pool of projects

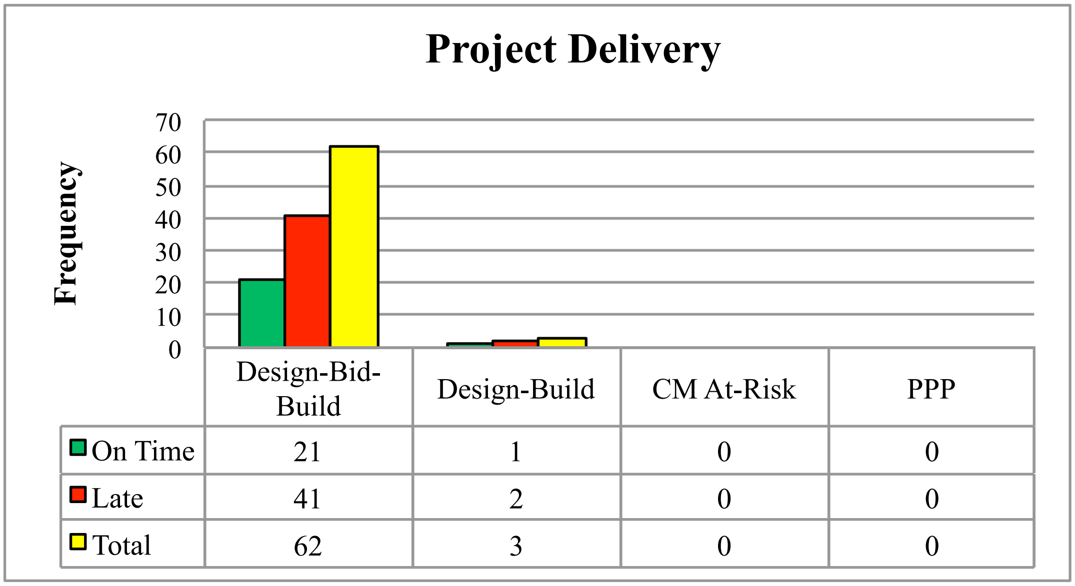


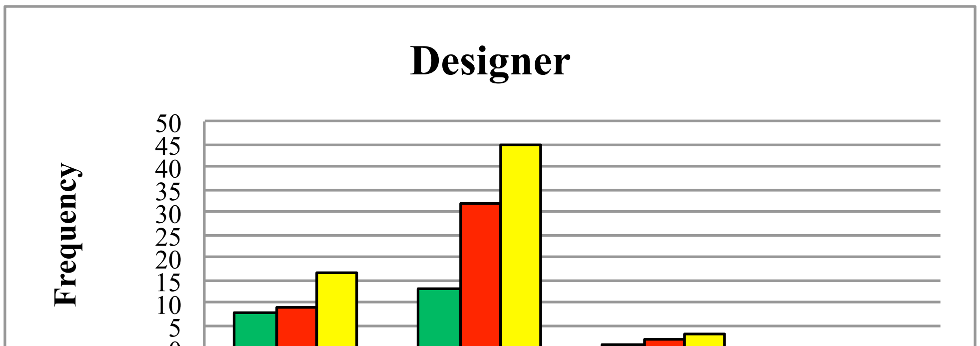
Figure 65 - Bar chart and table for Project Delivery

Table 25- OR and RR values for Project Delivery

Odds Ratio (OR) and Relative Risk (RR) for Project Delivery									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Project Delivery	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
DBB	41	21	2	1	0.98	1.00	-0.02410	1.25380	-2.48154	2.43335	0.084	11.397
DB	2	1	41	21	1.02	1.02	0.02410	1.25380	-2.43335	2.48154	0.088	11.960
CM At-Risk	0	0	43	22								
PPP	0	0	43	22								

5.5.1.8 Designer

The Designer category describes the group that executed the design tasks and prepared the contract documents. It is not necessarily the designer of record. There were 4 choices listed in the survey questionnaire. These included in-house, consultant, design-builder, and contractor alternate. Of the final pool, 17 or 26.15% of the projects were designed in-house. Of these, 8 were completed on time and 9 finished late. Consultants completed the design work for 45 or 69.23% of the projects; 13 of which were finished on time and 32 were finished late. Three or 4.62% of the designs were completed by a deign-builder, aligning with the 3 projects that utilized DB project deliver. Of these 3 projects, 1 finished on time and 2 finished late. Figure 66 includes the bar chart and table presenting the survey results and Table 26 lists the OR and RR values along with the SE and 95% C.I. for the OR for the designer category.



	In-house	Consultant	Design-builder	Contractor Alternate
On Time	8	13	1	0
Late	9	32	2	0
Total	17	45	3	0

Figure 66 - Bar chart and table for Designer

Table 26 - OR and RR values for Designer

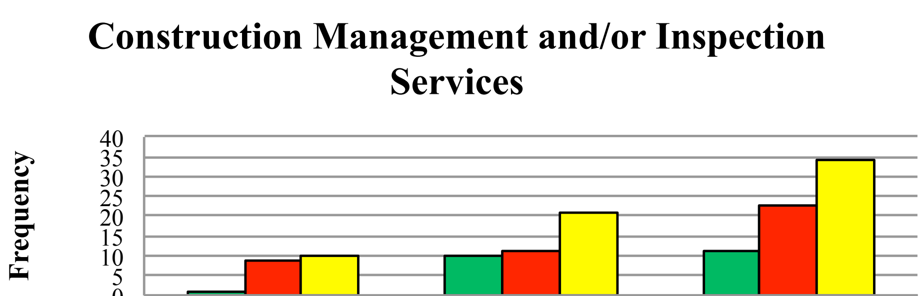
Odds Ratio (OR) and Relative Risk (RR) for Designer									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Designer	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
In-house	9	8	34	14	0.46	0.58	-0.76952	0.58048	-1.90725	0.36821	0.148	1.445
Consultant	32	13	11	9	2.01	1.26	0.70012	0.55695	-0.39151	1.79174	0.676	6.000
Design-Builder	2	1	41	21	1.02	1.02	0.02410	1.25380	-2.43335	2.48154	0.088	11.960

The Chi-square test results include χ^2_{STAT} = 1.8197 being less than χ^2_{CRIT} = 5.9915, with p = 0.4026 significantly greater than α = 0.05 at 2 *df.* Chi-square testing indicated that these proportions are not significantly different. However, note from Table 21 that utilizing consultants to design the project appears to increase the risk of time escalation with OR and RR values of 2.01 and 1.26, respectively. Keeping the work in-house appears to have the inverse effect, having OR and RR values of 0.46 and 0.58.

5.5.1.9 Construction Management and/or Inspection Services

The Construction Management and/or Inspection Services category sorts project into groups that provided the on site quality control and owner representation. It answers the question "who" was the Engineer's project representative in the field. The 3 choices on the survey questionnaire include consultant, owner, or an owner lead team. Figure 67 includes the bar chart and table presenting the survey results and Table 27 lists the OR and RR values along with the SE and 95% C.I. for the OR for the Construction Management and/or Inspection Services category. Of the 10 or 15.38% of the projects that were under the charge of consultants, 1 finished on time and 9 finished late. Owners' who provided this service strictly in-house accounted for 21 or 32.31% of the final pool. Of that, 10 projects finished on time and 11 finished late. The remainder of the pool included teams that were led by the owner; that is a direct agency employee(s) supplemented by consultant staff. These projects accounted for 34 or 52.31% of the final pool. Of those, 11 finished on time and 23 were completed late.

The Chi-square test results include χ^2_{STAT} = 4.3526 being less than χ^2_{CRIT} = 5.9915, with p = 0.1135 significantly greater than α = 0.05 at 2 *df.* Chi-square testing indicated that these proportions are not significantly different. However, as indicated in Table 22, the risk of time escalation is substantially greater for consultants than for the other two groups. This discrepancy required additional investigation.



	Consultant	Owner	Owner Lead w/ Consultant
On Time	1	10	11
Late	9	11	23
Total	10	21	34

Figure 67 - Bar chart and table for CM & Inspection Services

Table 27 OR and RR values for CM/Insp Services

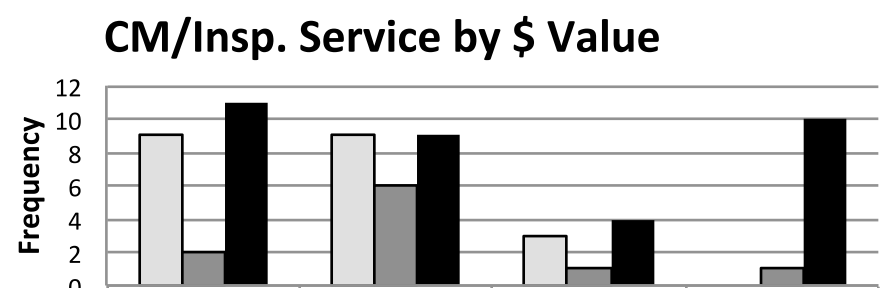
Odds Ratio (OR) and Relative Risk (RR) for Construction Mgt. and/or Inspection									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
CM/Insp Services	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
Consultant	9	1	34	21	5.56	4.60	1.71539	1.09002	-0.42105	3.85182	0.656	47.079
Owner	11	10	32	12	0.41	0.56	-0.88552	0.55271	-1.96884	0.19780	0.140	1.219
Owner Lead	23	11	20	11	1.15	1.07	0.13976	0.52469	-0.88862	1.16815	0.411	3.216

The first thought in approaching this concern is the perception that consultants are often contracted to provide construction field services on larger, more complex projects. However, review of the data does **not** support this belief for the sample final pool. Figure 68 is a bar chart plot of the construction management and/or inspection service providers sorted by size/range: $ value of projects. The chart shows the weaker performance of consultants alone compared to the other two groups. Further review revealed a large gap between the mean TPI values from projects in which consultants provided the CM/inspection services vs. the aggregated mean TPI value for the other service providers. The mean TPI for consultants was 0.732 compared to 0.876 for the combined other two groups.

The mean semantic differential ranking of complexity for projects covered by consultants was 4.600. The same metric for the aggregation of the other two groups was 4.908, which is 0.308 higher than for consultant projects. This indicates that on average, the projects covered by consultants were actually less complex than those covered by the other two groups. Therefore, the initial explanation of size/value and/or complexity for the higher risk associated with consultants does not appear plausible.

Further review revealed that the owner for 7 of the 10 projects were the Bears. The Lions were the owner agency for other 2 projects and the Tigers for one project covered by consultants. All 7 of the Bears projects covered by consultants finished late. It has already been established earlier in this thesis that the projects contributed to the

HPP Study from Bears are different from the sector of projects submitted by the other agencies, excluding the Lions[83].



	2-4 Million	5-20 Million	21-35 Million	>35 Million
Owner	9	9	3	0
Consultant	2	6	1	1
Owner Lead	11	9	4	10

Figure 68 - Bar chart and table for CM/Insp by $ Value

The increased risk of duration escalation for projects that are covered by consultant CM/inspection teams may simply be higher as a result of assignment to projects completed for the Bears. There is also the possibility that consultant teams either fail to provide the same level of service as the other CM/inspection groups or in some way impede the timely execution of construction. That scenario does not seem likely, at least not on the scale necessary to so dramatically affect risk of duration escalation. The difference in performance observed for the Bears compared to the rest of the pool will be considered in greater depth further on in this thesis.

[83] Recall that the final pool of projects is divided into three sectors: Lions, Tiger, and Bears and eventually into two categories: Ligers and Bears

5.6 Contract and Performance Data

Contracts and performance data was obtained typically through open-ended questions in the survey questionnaire. The data under this heading are related to either time or cost.

5.6.1 Time Performance Data

The requested information included the First Chargeable Day and the Contract Completion Date, which were useful in determining qualification for the study pool and validating durations. Incongruence between dates and reported durations prompted review for further validation. Even after validation, the dates did not always align with the durations. This was due to different approaches to tracking time across the various agencies. The original contract duration (OCD) and the final construction duration (FCD), both listed in calendar days, were verified. These data were critical to the HPP Study since the quotient of the OCD divided by FCD is the central performance indicator of interest; TPI.

The OCD CD values obtained through the survey ranged from 120 to 1,624 with mean of 688 and median of 551. The FCD CD values obtained ranged from 120 to 1,962 with a mean of 811 and median of 678. The maximum values are the equivalent of 4.45 and 5.38 years. The difference between the mean OCD and the mean FCD, Δt, was -123 CDs. This mean differential between the OCD and FCD is the equivalent of approximately 4 months of duration escalation. The duration data are summarized in Table 28. The table includes CDs converted to weeks, months, and years.

Table 28 - Project Duration Summary

Project Duration Data Summary													
Statistic	OCD				FCD				Δ_t				
	CDs	Weeks	Months	Years	CDs	Weeks	Months	Years	CDs	Weeks	Months	Years	Δ_{TIME}%
Minimum	120	17.1	3.95	0.33	120	17.1	3.95	0.33	0	0.0	0.00	0.00	0.00%
Maximum	1,624	232.0	53.39	4.45	1,962	280.3	64.50	5.38	-338	-48.3	-11.11	-0.93	-20.81%
Range	1,504	214.9	49.45	4.12	1,842	263.1	60.56	5.05	-338	-48.3	-11.11	-0.93	-22.47%
Mean	688	98.3	22.62	1.88	811	115.9	26.68	2.22	-123	-17.6	-4.06	-0.34	-17.94%
Std. Deviation	383	54.7	12.59	1.05	459	65.6	15.09	1.26	-76	-10.9	-2.50	-0.21	-19.88%
Median	551	78.7	18.12	1.51	678	96.8	22.27	1.86	-127	-18.1	-4.16	-0.35	-22.96%

The next question asked *Based on the original scope of work without considering the effect of weather, was the original contract duration reasonable and achievable?* The choices provided were discrete yes or no responses. There were 60 responses to the question from the final pool of survey responses. Of these, 57 indicated in the affirmative and 3 that the original contract durations were unachievable. Respondents therefore believed that of the 40 that experienced duration escalation, 37 or 92.5% of those projects' original scope of work could have been completed within the OCD. This of course, is excluding the impact of inclement weather.

5.6.2 Time Extensions

Respondents were asked to list the time extension granted to the contractor and to also identify extension granted for weather delays. Time extension (TE) were granted on 40 of the final pool projects, 36 of which finished beyond the OCD. TE was granted but not needed or used for 2 projects. Of the 36 late performers granted an extension, the TE matched Δt for 20 of those projects. Of the late projects granted TE, the TE was actually greater than Δt. In other words, the owner granted more additional contract time than was consumed by the contractor.

TE was granted for weather delays (WD) on 9 projects, 2 of which were completed on time and actually did not need the extended time to complete the work within the OCD. Seven (7) or 16.28% of late projects granted TE included time for weather delays. Five (5) of the projects had TE values equal to WD; meaning that the entire excusable time escalation was related to weather. This included Internal Ref. #'s 22, 23, 25, 66, and 67. The effects of adverse weather shall be considered in the comparative analyses to follow. The FCD shall be adjusted by subtracting from it the value of WD, yielding FCD_W. In other words, $FCD_W = FCD – WD$. The TPI will then be adjusted or the projects affected by weather, where $TPI_W = OCD/FCD_W$. The TPI_W metric will replace TPI as the dependent variable in comparative analyses assessing the impact of key performance indicators.

5.7 Cost Performance Data

Original contract dollar values (OCV) in the final pool ranged from \$528,653 to \$144,555,441 with a mean value of 19,583,061 and median of 9,791,208. The final (actual) contract values (FCV) ranges from \$528,653 to \$155,450,000 with a mean value of 20,551,313 and median of 9,622,038. The mean Δ_{COST}% was -6.1 for a PPI = 0.956. The maximum post-award cost growth (lowest value of Δ\$) was \$13,357,016 on a project with an OCV of \$49,547,857, resulting in a Δ_{COST}% of -27.0%. The cost variance metric, Δ\$, is the difference between the original contract and final values and is computed as Δ\$ = OCV – FCV. A negative value for Δ\$ indicates post-award cost growth. Conversely, a positive value for Δ\$ indicates that the project was completed at a price under or less than the OCV[84]. The metric, $\Delta_{COST}\%$, is the difference between the original and final contract values as a percentage of the original contract value and is computed as $\Delta_{COST}\% = (\Delta\$/OCV) \times 100$. The largest post-award cost growth in terms of $\Delta_{COST}\%$ was 88.1% from a Δ$ of $4,249,254 on an OCV of $4,822,744. Table 29 provides a summary of the project cost data.

Table 29 - Project cost data summary

Project Cost Data Summary				
Statistic	Original Contract Value: $	Actual/Final Contract Value: $	Δ$	$\Delta_{COST}\%$
Minimum	528,653	528,653	0	0.00%
Maximum	144,555,441	155,450,000	-10,894,559	-7.54%
Range	144,026,788	154,921,347	-10,894,559	-7.56%
Mean	19,583,061	20,551,313	-968,252	-4.94%
Std. Deviation	25,835,612	27,551,083	-1,715,471	-6.64%
Median	9,791,208	9,622,038	169,170	1.73%

5.7.1 Liquidated Damages

Other cost considerations in the HPP Study included evaluation of liquidated damages (LD) for late completion. Liquidated damages are a remedy for breach of contract, more specifically late completion beyond the stipulated duration. While the courts have held that liquidated damages cannot be punitive, they are viewed as a mechanism for encouraging timely completion. The questionnaire asked *what daily amount was listed for liquidated damages in the contract documents*? The responses were evaluated in a

[84] The phrase "under budget" is often used when Δ$ is positive. The term "budget" can have different meanings and will be avoided when discussing the Δ$ and $\Delta_{COST}\%$ metrics in this thesis.

table titled *Liquidated Damages - Data Analysis*, the full output of which is available in the appendix. Table 30 provides a summary of the analysis.

Table 30 - Summary of Liquidated Damages

Summary of Liquidated Damages Data Analysis					
Statistic	LD	LD as % of OCV	TPI_{LD}	$TPI_{LD - TPI65}$	LD Strength Factor
Maximum	50,000	0.10%	1.348	0.489	0.802
Minimum	400	0.00%	0.447	-0.412	-2.186
Range	49,600	0.10%	0.900	0.900	2.988
Mean	3,725	0.03%	0.908	0.049	-0.052
Std. Deviation	6,994	0.02%	0.197	0.197	0.605
Median	2,000	0.02%	0.932	0.073	0.022

The reader should recognize that the statistics in cells to the right are not computed from adjoining cells on the left, but are the static for the column. Side-by-side comparisons can be made from the full table in the appendix. The table includes columns listing the Internal Reference #, LD (Liquidated damages daily dollar value), LD as % of OCV, TPI_{LD} (TPI for the project), $TPI_{LD} - TPI_{65}$ (where $TPI_{65} = 0.859$), and a metric referred to as LD Strength Factor. The LD Strength Factor was conceived by the author to measure the effect of the LD as % of OCV has upon TPI_{LD} - TPI_{65}. The LD Strength Factor is simply the quotient of LD as % of OCV/ $TPI_{LD} - TPI_{65}$ multiplied by 100 for greater visibility. Correlation analysis using Minitab 16 was performed on the full data sets including LD as % of OCV, $TPI_{LD} - TPI_{65}$, and LD Strength Factor. Table 31 is the Minitab output of the correlation analysis.

Table 31 - Minitab output of correlation comparisons of LD values

Correlations: LD as % of OCV, TPILD - TPI65, LD Strength Factor

	LD as % of OCV	TPILD - TPI65
TPILD - TPI65	-0.186	
	0.191	
LD Strength Fact	0.242	-0.238
	0.087	0.093

Cell Contents: Pearson correlation
P-Value

Table 31 shows that the LD as % of OCV compared against $TPI_{LD} - TPI_{65}$ yields a Pearson correlation, r, of -0.186 at p = 0.191, comparison of LD as % of OCV against LD Strength Factor results in r = 0.242 at p = 0.087, and the comparison of $TPI_{LD} - TPI_{62}$ against LD Strength Factor results in r = -0.238 at p = 0.093. Since all of the p-values are greater than $\alpha = 0.05$, the H_0 that r = 0 cannot be rejected. Therefore, the decision is that no correlation exists between the parings of the LD data. The author's interpretation is that LD had a negligible effect on the TPI. The presence of LD did not seem to encourage timely completion.

5.7.2 The Effect of Bid Gap

Highway infrastructure contracts are typically procured through the sealed low-bid process. The difference between the winning low bid and second-place finisher can vary. This difference is frequently referred to as "bid gap". While competition can produce very small differences between the two bids, it is not an uncommon occurrence for there to be a notable difference[85]. It is a belief in the industry that large bid differences result in projects that are at higher risk in terms of quality, contractor cooperation, and claims. Of interest to this research is whether such bid gaps affect time performance. In response to this interest, the survey questionnaire included the interrogative statement *The winning bid was how much lower was how much lower than the 2nd place bid?*

Table 32 - Summary of Bid Gap

Summary -- Analysis of the Effect of Bid Gap						
Statistic	Bid Gap $	Bid Gap %	Δ 2nd pl. vs. FCV $	Δ FCV vs. 2nd place bid as % of FCV	TPI	PPI
Maximum	17,000,000	25.59%	6,640,942	36.66%	1.348	1.113
Minimum	8,133	0.11%	-11,322,873	-46.84%	0.447	0.624
Range	16,991,867	25.48%	17,963,816	83.50%	0.900	0.488
Mean	1,274,102	6.47%	40,722	0.81%	0.885	0.958
Std. Deviation	2,691,229	5.90%	2,566,288	14.22%	0.205	0.088
Median	481,200	4.63%	199,472	1.85%	0.916	0.980

The responses were placed into the master spreadsheet, with additional columns inserted to compute the second-place bid value and the difference between the two bids as a percentage of the winning bid. An additional table was generated to further analyze the bid data. It included columns for Δ between the second-place bid and the FCV in dollars and another for Δ FCV against the second place bid as % of FCV. The table also contained the TPI and PPI values for each of the projects included in the table. Table 32

[85] The colloquial expression for such occurrence is “leaving money on the table.

is a summary of the analysis of the effect of the bid gap. The full table is available in the appendix.

Table 33 - Minitab output from correlation analysis of bid gap

Correlations: Bid Gap $, Bid Gap %, Δ 2nd pl. vs, Δ FCV vs. 2n, ...

```
                         Bid Gap $         Bid Gap %  Δ 2nd pl. vs. FC
Bid Gap %                    0.272
                             0.049

Δ 2nd pl. vs. FC             0.352             0.208
                             0.010             0.134

Δ FCV vs. 2nd pl             0.339             0.031             0.285
                             0.013             0.825             0.039

Δ FCV vs. 2nd pl             0.339             0.031             0.285
                             0.013             0.825             0.039

TPI                         -0.196             0.019             0.139
                             0.159             0.890             0.323

PPI                         -0.099             0.122             0.645
                             0.479             0.383             0.000


                  Δ FCV vs. 2nd pl  Δ FCV vs. 2nd pl               TPI
Δ FCV vs. 2nd pl             1.000
                                 *

TPI                         -0.242            -0.242
                             0.080             0.080

PPI                          0.258             0.258             0.195
                             0.063             0.063             0.162

Cell Contents: Pearson correlation
               P-Value
```

The data from the full table was tested for correlation using Minitab 16. Figure 55 is the Minitab output from that run. The bid gap data pairings with TPI yielded r = -0.196 at p = 0.159, r = 0.019 at p = 0.890, r = 0.139 at p = 0.323, r = -0.242 at p = 0.080, and r = 0.195 at p = 0.162. Since all of the r-values are low and all p-values are greater than $\alpha = 0.05$, H_0 is not rejected. There does not appear to be correlation between the input variables from the bid gap data and the TPI. There does appear to be moderate correlation between some of the bid gap data variables that could warrant additional investigation. However, such investigation is beyond the scope of this study.

5.8 Constraints

Constraints in this particular context refer to anything physical, environmental, or legal in nature that can impede or restrict construction operations. Constraints in this sense can reduce productivity and efficiency and are believed to contribute toward duration escalation. Table 34 provides a summary of the constraints addressed in this study. Figure 69 presents a bar chart display of the constraints. The survey questionnaire provided 18 choices and 2 open-ended slots for “others”. One of those original 18 that appeared on the questionnaire, force majeure, had a total frequency of zero and was dropped from the study. The very small number of “others”, overlapped the constraints listed on the questionnaire and were placed in the appropriate bin during initial validation.

Table 34 - Constraints Summary

Constraints Summary			
Constraint	**Performance Frequency**		
	On Time	**Late**	**Total**
Phased MOT	9	28	37
Stream/Waterway	9	27	36
Utilities	7	29	36
Physical Space	8	17	25
Wetlands	7	18	25
Winter Shutdown	6	17	23
Fish/wildlife	6	9	15
E. Mitigation	5	10	15
Holidays	4	11	15
Railroad	2	11	13
Navigation	4	5	9
Historic Landmark	3	6	9
Archeological	3	2	5
Union Contract	2	3	5
Noise Ordinance	1	3	4
Parklands	1	2	3
Built Environ.	1	2	3

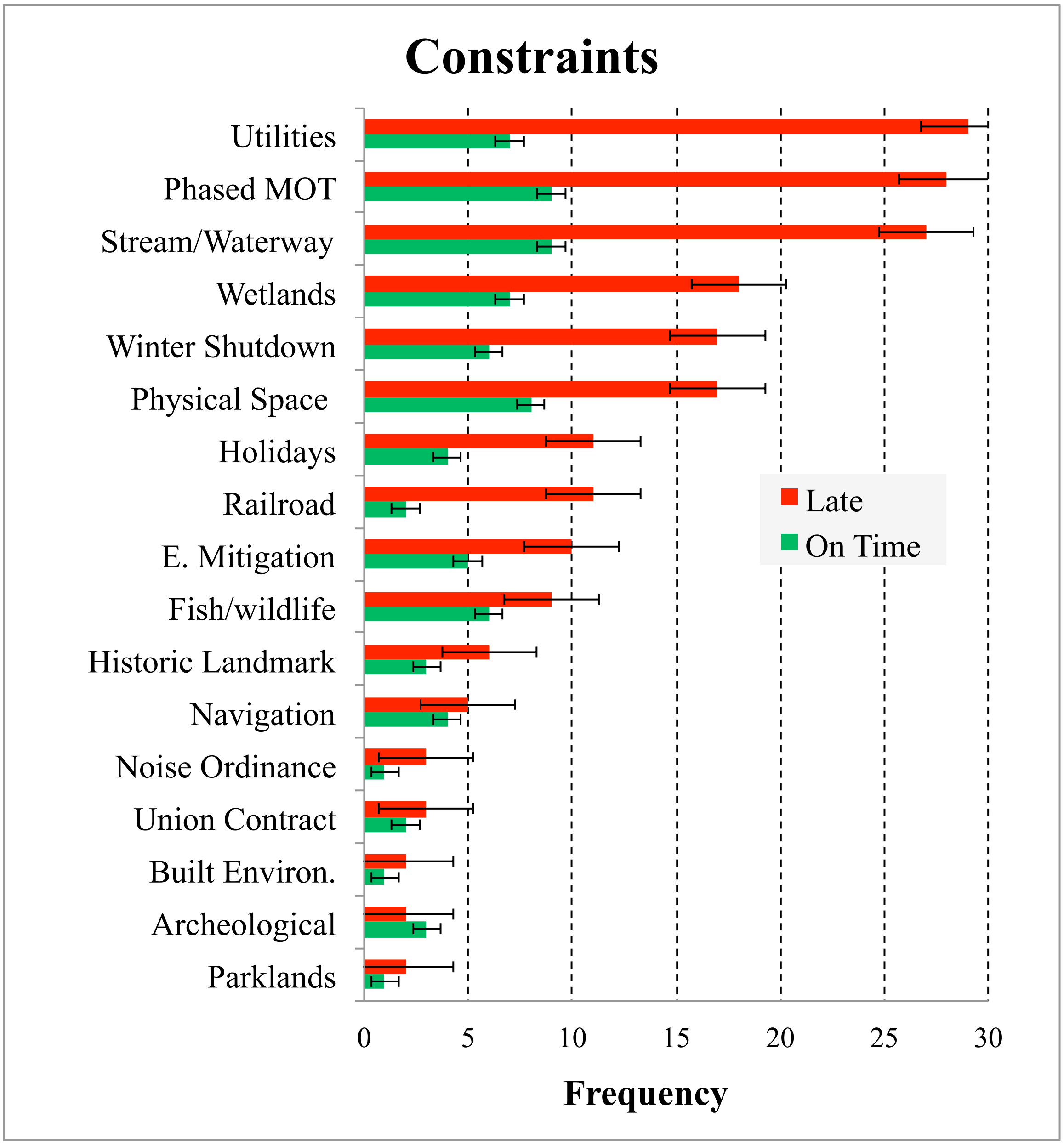


Figure 69 – Horizontal Bar Chart displaying Constraints

Table 347 and Figure 69 identify the frequencies for these constraints, but further investigation was necessary determine the risk they pose on projects in terms duration escalation. The initial test applied to the constraints data was the Chi-square procedure to test for differences in proportions; specifically between late and on time performers.

Recall that the null hypothesis, H_0, states that there is no difference between specified proportions. The alternate hypothesis, H_1, is that there is a significant difference. A 2 x 2 test was run for each constraint at a level of significance $\alpha = 0.05$ at 1 *df*.

Table 35 is a summary of the Chi-square tests performed on the constraint data sets. Full outputs from each of these runs are available in the appendix. As noted in the test summary, the decision from the tests of projects affected by Utilities and Union Contracts was to reject the null hypothesis, indicating significant difference. The projects exposed to these three constraints appear to be at greater risk of duration escalation than those not exposed.

Table 35 - Summary of Chi-Square test on Constraints

Chi-Square Test Summary - Constraints

Constraint	*r*	*c*	*df*	χ^2_{CRIT}	χ^2_{STAT}	*p*-Value	Decision
Wetlands	2	2	1	3.8415	0.6201	0.4310	Do not reject the null hypothesis
Parklands	2	2	1	3.8415	0.0004	0.9847	Do not reject the null hypothesis
Archaeological	2	2	1	3.8415	1.6548	0.1983	Do not reject the null hypothesis
Historic Landmark	2	2	1	3.8415	0.0012	0.9721	Do not reject the null hypothesis
Fish/Wildlife	2	2	1	3.8415	0.3298	0.5658	Do not reject the null hypothesis
Stream/Waterway	2	2	1	3.8415	2.8201	0.0931	Do not reject the null hypothesis
Navigation	2	2	1	3.8415	0.5241	0.4691	Do not reject the null hypothesis
Winter Shutdown	2	2	1	3.8415	0.9571	0.3279	Do not reject the null hypothesis
Phased MOT	2	2	1	3.8415	3.4780	0.0622	Do not reject the null hypothesis
Physical Space	2	2	1	3.8415	0.0618	0.8036	Do not reject the null hypothesis
Built Environment	2	2	1	3.8415	0.0004	0.9847	Do not reject the null hypothesis
Noise Ordinance	2	2	1	3.8415	0.1490	0.6995	Do not reject the null hypothesis
Utilities	2	2	1	3.8415	7.4745	0.0063	**Reject the null hypothesis**
Holidays	2	2	1	3.8415	0.4489	0.5029	Do not reject the null hypothesis
Environmental Mitigation	2	2	1	3.8415	0.0023	0.9618	Do not reject the null hypothesis
Railroad	2	2	1	3.8415	2.4736	0.1158	Do not reject the null hypothesis
Union Contract	2	2	1	3.8415	37.3702	0.0000	**Reject the null hypothesis**

Notes:
(1) The expected frequency assumption was met in testing for all constraints

The next test procedure was computation of the OR, RR, and related statistics for each individual constraint. Table 36 is the output from those computations. Notice from the table that Phased MOT and Utilities exhibit relatively higher OR and RR values. This is consistent with results of the Chi-square test. Utilities have OR and RR values of 4.45 and 2.12 and Phased MOT has 3.00 and 1.65. Projects impacted by railroads and streams or waterways are also appearing to be at higher risk of duration escalation. The presence of wetland and noise ordinances also appears to impose higher risk of duration escalation. OR and RR statistics could not be generated because of the presence of zero in one of the cells.

Table 36 - OR and RR values for Constraints

Odds Ratio (OR) and Relative Risk (RR) for Constraints for All Projects									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Constraint	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
Wetlands	18	7	25	15	1.54	1.32	0.43364	0.55234	-0.64895	1.51622	0.523	4.555
Parklands	2	1	41	21	1.02	1.02	0.02410	1.25380	-2.43335	2.48154	0.088	11.960
Archaeological	2	3	41	19	0.31	0.34	-1.17460	0.95413	-3.04468	0.69549	0.048	2.005
Historic Landmark	6	3	37	19	1.03	1.02	0.02667	0.76135	-1.46558	1.51892	0.231	4.567
Fish/Wildlife	9	6	34	16	0.71	0.77	-0.34831	0.60802	-1.54003	0.84341	0.214	2.324
Stream/Waterway	27	9	16	13	2.44	1.53	0.89097	0.53626	-0.16009	1.94204	0.852	6.973
Navigation	5	4	38	18	0.59	0.64	-0.52407	0.72930	-1.95349	0.90535	0.142	2.473
Winter Shutdown	17	6	26	16	1.74	1.45	0.55595	0.57136	-0.56392	1.67581	0.569	5.343
Phased MOT	28	9	15	13	2.70	1.59	0.99188	0.53890	-0.06437	2.04813	0.938	7.753
Physical Space	17	8	26	14	1.14	1.09	0.13473	0.54195	-0.92750	1.19696	0.396	3.310
Built Environment	2	1	41	21	1.02	1.02	0.02410	1.25380	-2.43335	2.48154	0.088	11.960
Noise Ordinance	3	1	40	21	1.58	1.53	0.45426	1.18573	-1.86977	2.77828	0.154	16.091
Utilities	29	7	14	15	4.44	2.12	1.49038	0.56164	0.38957	2.59119	1.476	13.346
Holidays	11	4	32	18	1.55	1.41	0.43624	0.65400	-0.84560	1.71807	0.429	5.574
Environ. Mitigation	10	5	33	17	1.03	1.02	0.02985	0.62380	-1.19280	1.25250	0.303	3.499
Railroad	11	2	32	20	3.44	2.81	1.23474	0.81985	-0.37217	2.84166	0.689	17.144
Union Contract	3	0	40	22								

The OR and RR statistics are good indicators of elevated risk resulting from exposure to a condition, i.e.: constraint. Binary logistic regression is a test that uses OR approach in modeling to predict probability of a categorical response for a given set of independent variables. This is essentially the combined OR for multiple factors. Rather than use TPI, the categorical response was whether the project finished late, where 0 = no and 1 = yes. The categorical input variables follow the same form in that 1 represents that the constraint was present. The test produces a logistic regression equation from which the estimated probability of an event can be computed. The logistic regression equation follows the form $\ln(OR) = b_o + b_1X_1 + b_2X_2 + \ldots + b_kX_k$. The estimated OR equals $e^{\ln(OR)}$. The estimated probability of an event is simply computed by dividing OR by the sum of 1 plus OR.

Minitab 16 was used to perform the logistic regression runs. Several runs were performed on various combinations of constraints. The highest estimated risk of duration escalation resulted from the simultaneous input of Stream/Waterway, Phased MOT, Utilities, and Railroad constraints. The Minitab output from that run is shown in Table 37. The resulting logistic regression equation using these constraints as input against late completion was ln(OR) = -0.79226 + 0.58506(1) + 0.49648 (1) +1.09187(1) +1.44596 (1) = 2.82711. The OR was calculated by $e^{2.82711}$ which equals 16.90; a value that should generate concern for those tasked with building a project with concurrent exposure of these 4 constraints[86]. The estimated probability of late completion is 16.90/(1 + 16.90), which equals 0.944. In other words, projects of this type under these constraints have a 94% likelihood that they will finish late. The final step in this test is to check for goodness-of-fit for the model. H_0: the model is a good fit, H_1: the model is not a good fit.

[86] While this combination of constraints yielded the largest OR and appears to be the worst case scenario, the author actually served as the Resident Engineer on such a project located near Newark, DE.

Table 37 – Minitab output of Logistic Regression for Constraints

Binary Logistic Regression: TPI versus Stream/Waterway, Phased MOT, ...

Link Function: Logit

Response Information

Variable	Value	Count	
TPI	1	43	(Event)
	0	22	
	Total	65	

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-0.792255	0.543467	-1.46	0.145			
Stream/Waterway	0.585056	0.604430	0.97	0.333	1.80	0.55	5.87
Phased MOT	0.496476	0.594123	0.84	0.403	1.64	0.51	5.26
Railroad	1.09187	0.917119	1.19	0.234	2.98	0.49	17.98
Utilities	1.45596	0.602785	2.42	0.016	4.29	1.32	13.98

Log-Likelihood = -35.305
Test that all slopes are zero: G = 12.591, DF = 4, P-Value = 0.013

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	5.87016	7	0.555
Deviance	7.65018	7	0.364
Hosmer-Lemeshow	3.69943	6	0.717

Table of Observed and Expected Frequencies:
(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group								
Value	1	2	3	4	5	6	7	8	Total
1									
Obs	2	4	4	6	7	4	10	6	43
Exp	2.8	3.9	3.4	4.7	7.6	4.7	9.2	6.6	
0									
Obs	7	5	2	1	3	2	1	1	22
Exp	6.2	5.1	2.6	2.3	2.4	1.3	1.8	0.4	
Total	9	9	6	7	10	6	11	7	65

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	679	71.8	Somers' D	0.51
Discordant	196	20.7	Goodman-Kruskal Gamma	0.55
Ties	71	7.5	Kendall's Tau-a	0.23
Total	946	100.0		

The most appropriate method of determining goodness-of-fit is by checking the p-value for the deviance statistic. If H_0 is less than 0.05, H_0 must be rejected. Otherwise, do not reject H_0. The p-value for the deviance statistic from this run was 0.364, which is greater than 0.05, therefore do not reject H_0. The model is good fitting.

5.9 Practices

Practices that were considered in the HPP Study include some that are highway industry specific and others that are more general and broadly applied to industries beyond infrastructure delivery. Practices are those techniques, methodologies, and processes applied to administer and execute highway construction projects. Those covered in this study include coordination with regulatory agencies, time management methodologies, innovative contracting methods or procedures, expediting strategies and post-construction review. Contemporary management paradigms including integrated project delivery (IPD), Lean principles, and Six-Sigma were included on the survey questionnaire with no affirmative responses that any of these had been employed on projects in the final pool.

The following subsections address each of the noted practices and include bar charts and contingency tables for on time and late project subsets and a combination of the two; all projects. The subsections also present discussions of the statistics and include results of Chi-square testing. OR and RR values have been computed for these practices as well.

5.9.1 Coordination with Regulatory Agencies

This category includes 3 regulatory agencies that can influence or restrict construction operations. Interaction with these agencies adds complexity to the project and this study sought to determine whether such interaction increases the risk if duration escalation. Figure 70 is a bar chart and table summarizing the survey results.

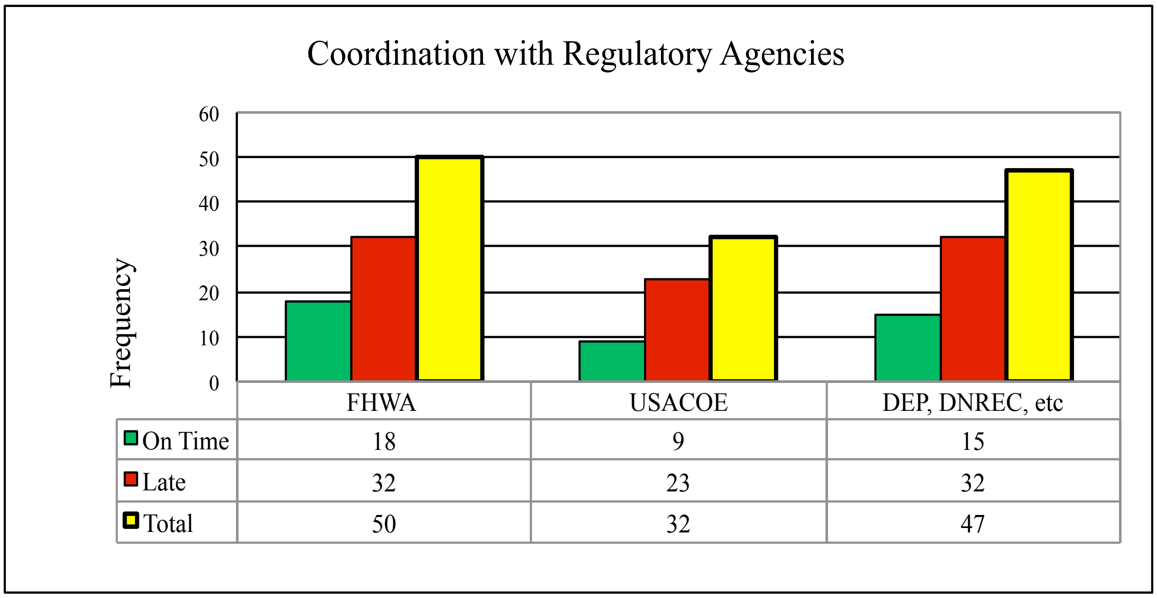


Figure 70 - Bar chart and table for Coordination w/Regulatory Agencies

Table 38 lists the OR and RR values along with the SE and 95% C.I. for the OR for coordination with regulatory agencies. Both values are <1 for interaction with FHWA. The risk is elevated when working with the State DEP at OR = 1.36 and RR = 1.09. and more so when working with USACOE, where OR = 1.66 and RR = 1.31.

Table 38 - OR and RR for Coordination w/ Regulatory Agencies

Odds Ratio (OR) and Relative Risk (RR) for Coord. w/Regulatory Agencies									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Regulatory Agencies	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
FHWA	32	18	11	4	0.65	0.91	-0.43624	0.65400	-1.71807	0.84560	0.179	2.329
USACOE	23	9	20	13	1.66	1.31	0.50749	0.53058	-0.53245	1.54742	0.587	4.699
DEP, DNREC, etc	32	15	11	7	1.36	1.09	0.30570	0.57592	-0.82310	1.43450	0.439	4.198

5.9.2 Time Management Methodologies

Time Management Methodologies addressed in the study include three contemporary techniques. The first, CPM Scheduling is quite common and is in fact a contract-required submittal for most public highway infrastructure projects. Linear Scheduling (LSM) is much less common in practice. The third, Last Planner™ is a relatively new methodology, which was developed through the Lean Construction movement. Figure 71 is a bar chart and table summarizing the survey results.

CPM was employed on 58 of the 65 projects in the final pool. LSM was used on 5 projects. There were no reported applications of Last Planner™ methodology for projects in the study pool. There was no time management methodology reported for 2 projects from the final pool, both of which finished on time. Table 39 lists the OR and RR values along with the SE and 95% C.I. for the OR for CPM and LSM Scheduling. The OR and RR for LSM are <1 indicating that there is a relatively lower risk using LSM as opposed to CPM.

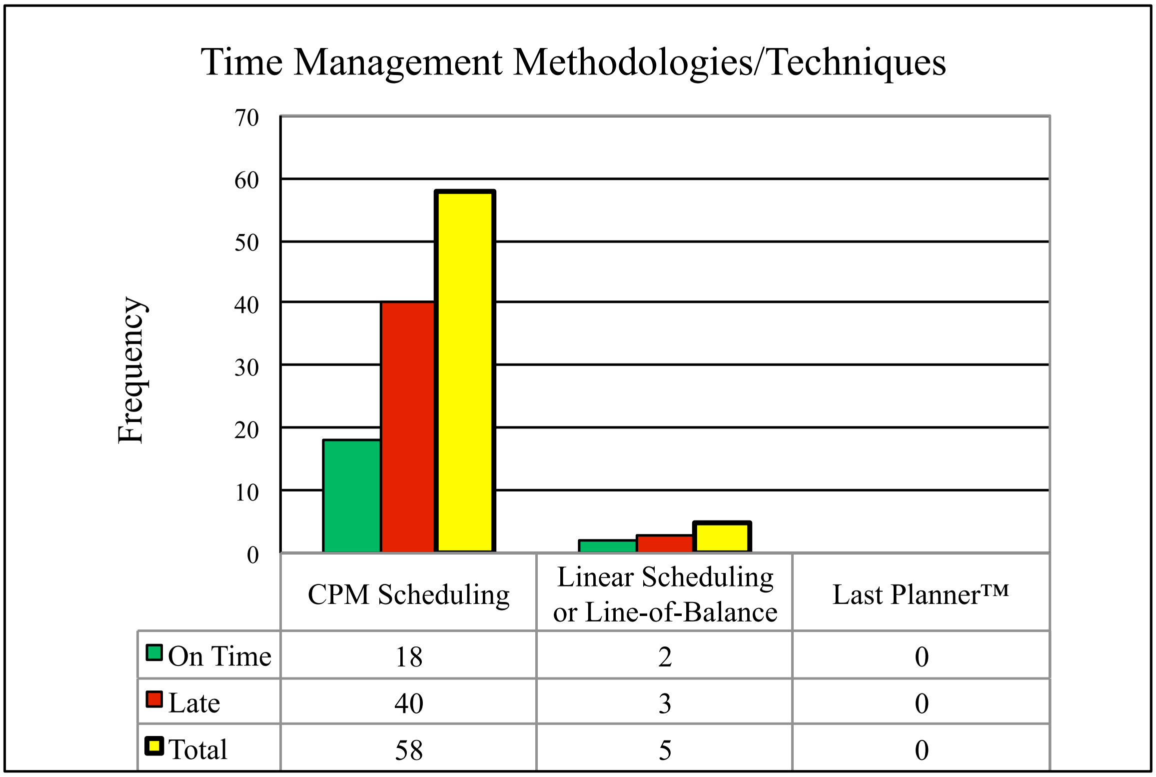


Figure 71 Bar chart and table for Time Mgt. Methodologies

Table 39 - OR and RR for Time Mgt. Methodologies

Odds Ratio (OR) and Relative Risk (RR) for Time Mgt. Methodologies									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Time Mgt. Methods	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
CPM Scheduling	40	18	3	4	2.96	1.14	1.08619	0.81479	-0.51081	2.68319	0.600	14.632
LSM or LOB	3	2	40	20	0.75	0.77	-0.28768	0.95307	-2.15569	1.58033	0.116	4.857
Last Planner™	0	0	43	22								

The Chi-square procedure was used to determine if there was a significant difference between the proportions. Table 40 is the Excel output from the test. The Chi-square test result included $\chi^2_{STAT} = 4.1984$, which is less than $\chi^2_{CRIT} = 5.9915$, with $p < 0.1226$ significantly greater than $\alpha = 0.05$ at 2 *df*. The decision is ***not*** to reject the null hypothesis. There does not appear to be a significant difference between the application of CPM and LSM. However, a strong declarative statement should not come from this result one way or the other. CPM was applied to a much greater extent than LSM by a factor of 11. What is important to note is that 43 out of 65 projects experienced duration escalation in spite of 63 of those projects employing formal time management, i.e. scheduling to manage time.

One of the postulates stated in the introduction of this thesis reads as follows:

> *The project management body of knowledge (PMBOK) contains widely accepted time management tools, yet judicious application of these does not effectively prevent duration escalation.*

The results from this study certainly do not support rejection of that postulate[87].

[87] The author does not wish to denigrate CPM methodology, just assess its true strengths and limitations. It is the author's opinion that CPM is a good and useful project management tool, not a panacea. Its judicious application does not ensure timely project completion. There are several risk factors leading to duration escalation, of which no scheduling process or software solution can affect.

Table 40 - Chi-square test of Time Mgt. Methodologies

Observed Frequencies - Time Management Methodologies				
	Performance			
Performance	CPM	LSM	None	Total
On Time	18	2	2	22
Late	40	3	0	43
Total	58	5	2	65

Expected Frequencies			pbar =	0.3385
	Performance			
Performance	CPM	LSM	None	Total
On Time	19.63	1.69	0.68	22
Late	38.37	3.31	1.32	43
Total	58	5	2	65

Data		Calculations		
Level of Significance	**0.05**	fo-fe		
Number of Rows	2	-1.63	0.31	1.32
Number of Columns	3	1.63	-0.31	-1.32
Degrees of Freedom	2			
		(fo-fe)^2/fe		
Results		0.13547	0.05594	2.58601
Critical Value	**5.9915**	0.06931	0.02862	1.32308
Chi-Square Test Statistic	**4.1984**			
***p*-Value**	**0.1226**			
Do not reject the null hypothesis				

Expected frequency assumption is violated.

5.9.3 Innovative Contracting Methodologies or Procedures

There were 8 practices identified as innovative contracting methodologies or procedure. These 8 are listed in Table 41. While these practices may not be new or truly innovative, the author's perception is that there is very limited application of some of these methodologies in the highway industry. The FHWA has been encouraging State highway agencies since 1992 to include contract clauses allowing contractors to submit a Value Engineering Change Proposal (VECP) (FHWA 2012). VECP's were submitted on 7 of the 65 projects in the study. Incentive/Disincentive Clauses and Constructability Studies were applied to 14 or 21.54% of the final pool of projects and were the innovative procedures with the greatest application in the study. Preconstruction Risk Management was applied to only two (2) projects.

Table 41 - Innovative Practices

Innovative Practice	On Time	Late	Total
Incentive/Disincentive	8	6	14
Best Value Procurement	0	3	3
Qualifications-based Selection	1	3	4
Lane Rental Method	1	1	2
Preconstr. VE Study	2	4	6
Contractor VECP	0	7	7
Constructability Study	7	4	11
Preconstr. Risk Assessment	0	2	2

Incentive/disincentive (I/D) clauses are provided in certain contracts where timely or even early completion is critical. Constructability studies are intended to improve the quality of the contract documents such that they support the smooth, safe flow of work while minimizing disruption and conflict. Poor constructability increases the risk of duration escalation. The analyses that follow are intended to identify factors that affect the risk of duration escalation, whether in a positive or negative fashion. The analyses will attempt to determine the efficacy of the I/D and VECP clauses as they were applied to the projects in the final pool. Table 42 lists the OR and RR values along with the SE and 95% C.I. for the OR for I/D, qualifications-based selection, lane rental, preconstruction VE study, and constructability study. The OR and RR values for the other procedures, including VECP, could not be computed due to the presence of zeros in the cells.

Table 42 - OR and RR values for Innovative Practices

Odds Ratio (OR) and Relative Risk (RR) for Innovative Practices									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Innovative Practice	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
Incentive/Disincentive	6	8	37	14	0.28	0.38	-1.25954	0.62460	-2.48375	-0.03533	0.083	0.965
Best Value Procurement	3	0	40	22								
Qualifications-based Selection	3	1	40	21	1.58	1.53	0.45426	1.18573	-1.86977	2.77828	0.154	16.091
Lane Rental Method	1	1	42	21	0.50	0.51	-0.69315	1.43925	-3.51407	2.12777	0.030	8.396
Preconstr. VE Study	4	2	39	20	1.03	1.02	0.02532	0.90865	-1.75563	1.80627	0.173	6.088
Contractor VECP	7	0	36	22								
Constructability Study	4	7	39	15	0.22	0.29	-1.51513	0.69654	-2.88034	-0.14991	0.056	0.861
Preconstr. Risk Assessment	2	0	41	22								

Note that with the minor exception of qualifications-based selection and Preconstruction VE Study, all of the factors imposed a much lower risk of duration escalation. Particularly notable is the low OR and RR values of 0.28 and 0.38 respectively for I/D. I/D dollar values are generally substantially higher than LD amounts. It appears that I/Ds did have a strong tendency to reduce the risk of duration escalation. Even so, 6 of the 14 or nearly 43% of the projects using I/Ds finished late. The Chi-square procedure was applied to check for differences in proportions between those projects that employed I/Ds and those that did not. The Excel output from that test is shown in Table 43.

Table 43 - Chi-square output for Incentive/Disincentive Clauses

Observed Frequencies			
	Incentive/Disincentive Clauses		
Performance	**Present**	**Not Present**	**Total**
On Time	8	14	22
Late	6	37	43
Total	14	51	65

Expected Frequencies		**p**bar =	0.3385
	Incentive/Disincentive Clauses		
Performance	**Present**	**Not Present**	**Total**
On Time	4.74	17.26	22
Late	9.26	33.74	43
Total	14	51	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**4.3251**
***p*-Value**	**0.0376**
Reject the null hypothesis	

Calculations	
fo-fe	
3.26	-3.26
-3.26	3.26
(fo-fe)^2/fe	
2.24496	0.61626
1.14858	0.31530

Expected frequency assumption is met.

The Chi-square test result was significant with $\chi^2_{STAT} = 4.3251$ being greater than $\chi^2_{CRIT} = 3.8415$, with $p < 0.0376$, a value less than $\alpha = 0.05$ at 1 *df*. Therefore, H_0 is rejected. There appears to be a significant difference between projects the employed I/Ds and those that did not. Considering the relatively small sample size based on a single survey, definitive conclusions should not be drawn regarding the efficacy of I/Ds in enhancing timely project delivery. However, this finding does suggest such efficacy.

Table 44 - Chi-square test output for Constructability Study

Observed Frequencies			
	Constructability Studies		
Performance	**Conducted**	**Not Conducted**	**Total**
On Time	7	15	22
Late	4	39	43
Total	11	54	65

Expected Frequencies		**pbar =**	0.3385
	Constructability Studies		
Performance	**Conducted**	**Not Conducted**	**Total**
On Time	3.72	18.28	22
Late	7.28	35.72	43
Total	11	54	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**5.2480**
***p*-Value**	**0.0220**
Reject the null hypothesis	

Calculations	
fo-fe	
3.28	-3.28
-3.28	3.28
(fo-fe)^2/fe	
2.88423	0.58753
1.47565	0.30060

Expected frequency assumption is met.

Table 44 is the Chi-square test output to compare projects, which were subjected to constructability studies against those that were not. The Chi-square test result was significant with $\chi^2_{STAT} = 5.2480$ being greater than $\chi^2_{CRIT} = 3.8415$, with $p < 0.0220$, a value less than $\alpha = 0.05$ at 1 *df*. Therefore, H_0 is rejected. There appears to be a significant difference between projects in which constructability studies were conducted and those that were not the subject of a constructability study. This difference suggests that conducting constructability studies may reduce the risk of duration escalation.

5.9.4 Contemporary Management Paradigms

The category includes Integrated Project Delivery (IPD), Lean Principles, Six-Sigma, and Total Quality Management (TQM). However, there were only 3 projects that employed TQM and these three points represented all of the data that was collected for this category. No further analysis was pursued.

5.9.5 Expediting Strategies

Expediting strategies often applied to road and bridge construction include precasting concrete elements, off-site prefabrication, and on-site prefabrication. A fourth rather unrelated strategy known as Hyper-Build was included in the survey, but yielded no data. Figure 72 includes the bar chart and table presenting the survey results. Table 45 lists the OR and RR values along with the SE and 95% C.I. for the Expediting Strategies. The OR and RR values for off-site prefabrication suggest that projects utilizing this expediting strategy may be at a higher risk of duration escalation than those that do not. That is not to say that the risk is necessarily attributable to these factors. Offsite work is often performed to allow concurrence of work paths without special interference a the jobsite, among many other reasons. However, utilizing offsite operation can introduce logistical complexity to the process.

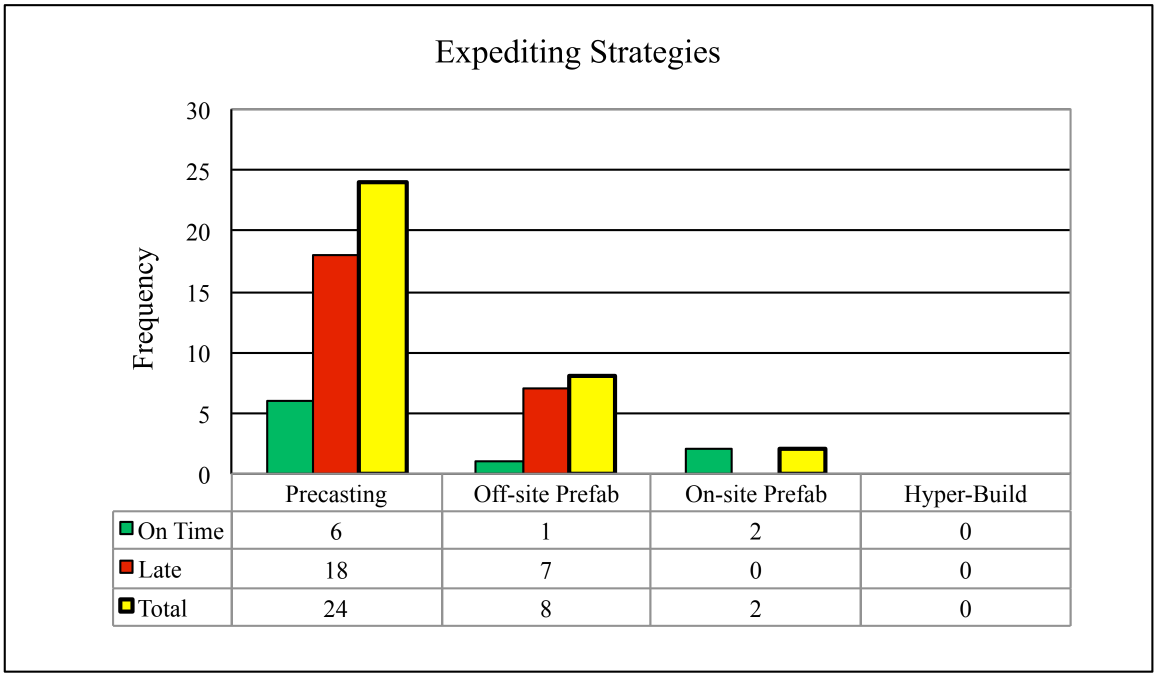


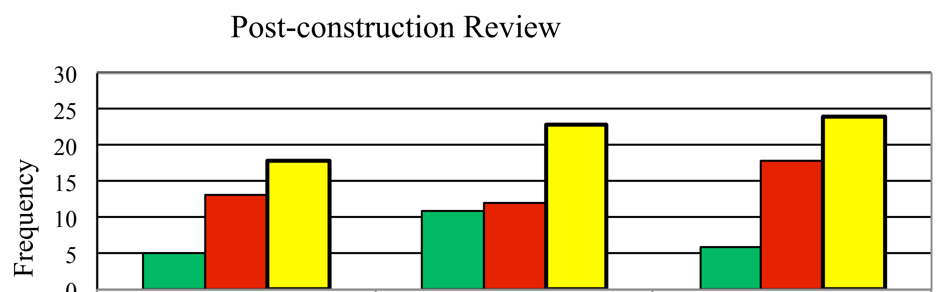
Figure 72 - Bar chart and table for Expediting Strategies

Table 45 - OR and RR values for Expediting Strategies

Odds Ratio (OR) and Relative Risk (RR) for Expediting Strategies									95% C.I., Z = 1.96			
Factor	Observations				Statistic				for lnOR		for OR	
Expediting Strategy	**a**	**b**	**c**	**d**	**OR**	**RR**	**lnOR**	**SE**	**Min**	**Max**	**Min**	**Max**
Precasting	18	6	25	16	1.92	1.53	0.65233	0.56984	-0.46457	1.76922	0.628	5.866
Off-site Prefab	7	1	36	21	4.08	3.58	1.40691	1.10375	-0.75643	3.57025	0.469	35.526
On-site Prefab	0	2	43	20	0.00	0.00						

5.9.6 Post-Construction Review

Post-construction review choices provided on the survey questionnaire included none, informal, and formal review capturing lessons-learned.



	None	Informal	Formal review w/lessons-learned
On Time	5	11	6
Late	13	12	18
Total	18	23	24

Figure 73- Bar chart and table for Post-construction review

Post-construction review is just that, after the fact post-mortem of the project. The process is one of value if performed in the context learning and continuous improvement. The author believes that while a final review is necessary, the exercise known as pluses and deltas should be conducted frequently throughout preconstruction and construction phases. Figure 73 includes a bar chart and table presenting Post-construction review frequencies.

5.10 Project Outcomes Data

This section summarizes two questions; what caused post-award cost growth and what caused duration escalation? The post-award cost survey choices listed 5 factors and one open-ended for identification of other reasons. There were 15 factors and one for “other” addressing duration escalation. The final count of fixed options based on responses is 12 factors. The sets contain data that are neither mutually exclusive nor exhaustive. For instance, it is certainly possible and even common for a project to experience multiple factors causing delay of no factors present at all. The summarized results are posted in the next two subsections.

5.10.1 Causes of Post-Award Cost Growth

Table 46 and Figure 74 display the reported causes of post-award cost growth. There were a total of 89 occurrences reported. Design change or plan revision(s) and differing site conditions both had reported frequencies of 23 or 59% of the 39 projects experiencing post-award cost growth. Each of these frequencies represents 25.8% of the reported occurrences. These two factors were present together on 10 projects, leaving individual occurrences at 13 each. This frequency pattern accounts for 36 projects. These two factors are actually failures of the preconstruction process, which negatively impacted the construction phase. In other words, 36 of the 39 with post-award cost growth, 92.3% were affected by failure of the preconstruction process to identify and mitigate construction risk.

Table 46 – Table summarizing causes of post-award cost growth

Causes of Post-Award Cost Growth	
Design change/plan revision(s)	23
Differing site conditions	23
Adjusted final quantities (net increase)	22
Other	12
Contractor claim/compensable delay	5
One or more indicated constraints	4
Total number of occurrences	89

Adjusted quantities caused post-award growth on 22 or 56.4% of projects that experienced post-award cost growth. Some adjustment of final quantities is normal and expected since road and bridge projects are usually unit price line item contracts. Gross adjustment requirements however, would qualify as a failure of the preconstruction process. Unfortunately, there was no mechanism in the survey questionnaire to enable distinction between normal, accepted deviation and gross deviation. Damages that the owner paid for claims made by the contractor indicate admission of fault. Therefore, the responsibility for the resulting post-award cost growth can be assigned to the owner.

Root cause of many construction claims can be traced to the preconstruction phase. However, some claims arise for causes that cannot reasonably be foreseen or mitigated during preconstruction. There was no mechanism in the survey questionnaire to enable distinction whether proper risk management in the preconstruction phase could have avoided the claim or if developed from events strictly related to construction, e.g.

behavior on the construction site such as owner interference. Claims are usually complex in nature and to address them in-depth is beyond the scope of this research.

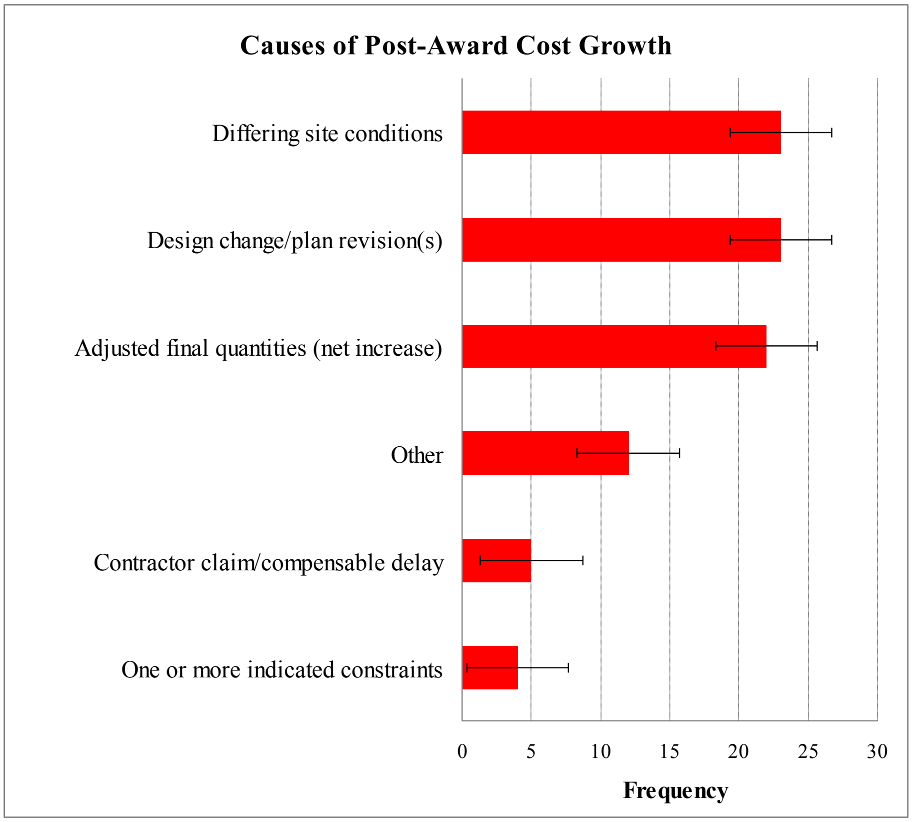


Figure 74 - Horizontal bar chart displaying reported causes of post-award cost growth

Responses for other causes of post-award cost growth include:

- Additional steel deterioration
- Final costs were less than original
- Asphalt/Diesel Fuel Adjustments
- Adjustments for diesel and asphalt were minimal
- Contaminated Material

- Incentive Payment $750,000
- Added Work

Of the other reported causes, additional steel deterioration most likely detectable during preconstruction but cannot be assumed to be the case. Fuel adjustments are beyond the control of either the owner or contractor and the resulting contract clauses are required to fairly distribute the associated risk. Added work on the other hand, is likely a failure of preconstruction even though it may seem to be failure of scope control during the construction phase.

In summary, it is reasonable to state that over 90% of post-award cost growth is attributable to failure to identify and mitigate risk in the preconstruction phase.

5.10.2 Causes of Duration Escalation

Table 47 and Figure 75 display the reported causes of duration escalation. There were a total of 88 occurrences reported in the fixed categories for causes of duration escalation. Owner requested changes occurred on 17 projects and differing/unforeseen site conditions occurred on 16 projects representing 37.5% of all fixed-category occurrences. There were multiple simultaneous occurrences as well as combined single occurrences. There were 15 occurrences of utility conflicts, 9 attributable to design errors or omissions, 10 due to weather impacts, 7 reported for poor contractor performance, poor constructability cited for 4 projects, lack of timely resolution 4 times, lack of commitment and upwardly adjusted final quantities cited twice (2) and right-of-way conflicts and unrealistic contract duration exhibiting one occurrence each. Of these, differing site conditions, owner requested changes, design errors and omissions, poor constructability, right-of-way conflicts, and unrealistic OCD are all traceable to the preconstruction phase. This total 48 or nearly 55% of all occurrences are attributable to failure to identify and /or mitigate risks during the preconstruction. Furthermore, they are the responsibility of the owner. Many of these failures were the fault of the projects' designer. Responsibility of design failures falls on the owner regardless of whether the design team was in-house or consultant.

Table 47 - Causes of Duration Escalation

Causes of Duration Escalation	
Owner requested design change	17
Differing or unforeseen site conditions	16
Utility conflict	15
Weather and seasonal impacts	10
Design errors or omissions	9
Poor contractor performance	7
Poor constructability	4
Lack of timely resolution of problems	4
Lack of commitment	2
Adjusted final quantities	2
Right-of-Way conflict	1
Unrealistic original contract duration	1

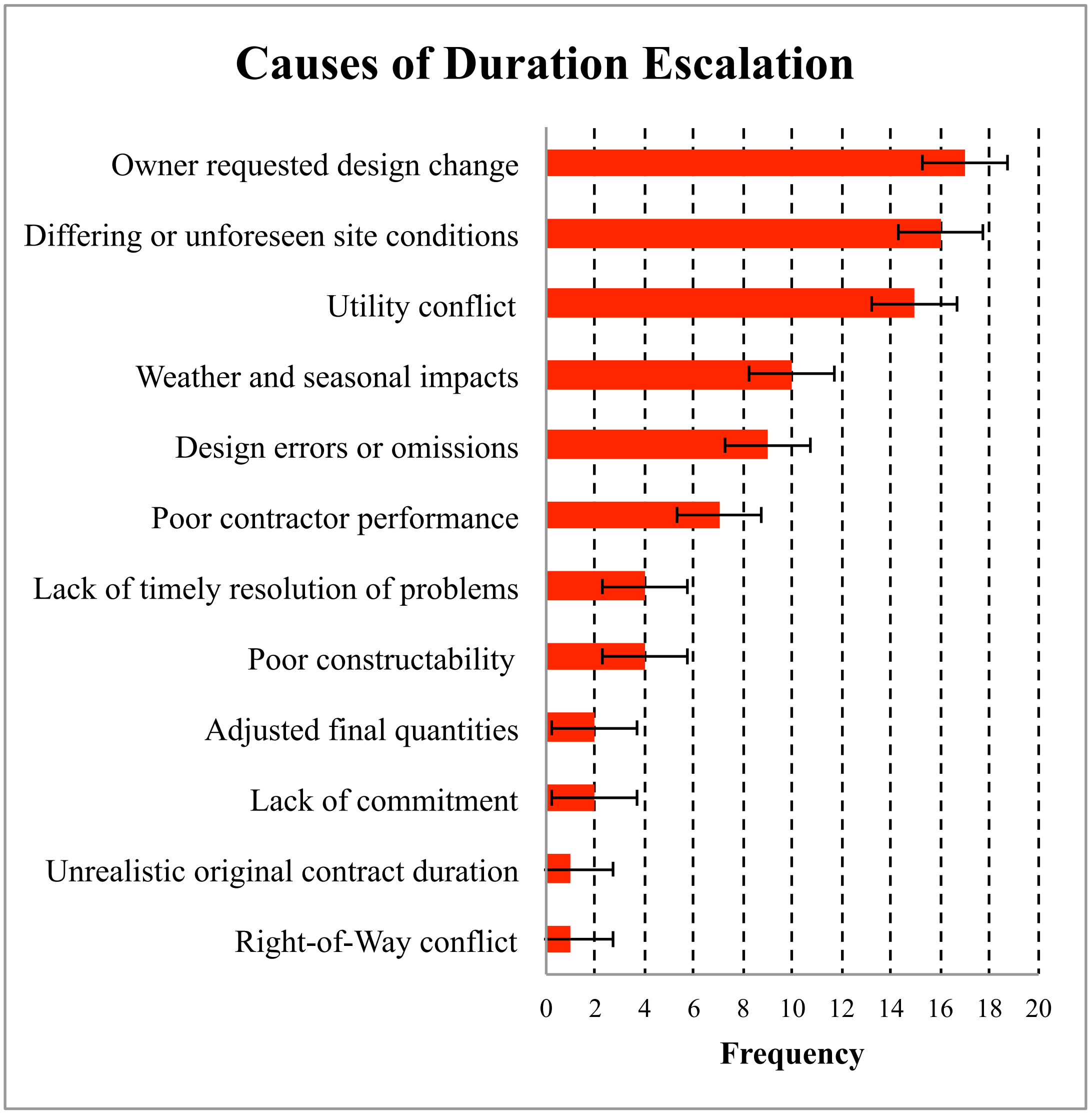


Figure 75 - Chart displaying Causes of Duration Escalation

It can be argued that utility conflicts are largely a failure of the preconstruction processes as well. As discussed earlier in this thesis, utility conflicts are often very complex issues, and affixing responsibility is not a simple matter. Whatever the case, the owner generally bears the risks associated with utility conflicts. Risks resulting from lack of timely resolution, regardless of level of designer involvement, generally fall on the owner, as does the impact of adjusted final quantities. This means that the owner bears the risks and is responsible for 69 or 78.4% of the reported occurrences, the vast majority attributable to failures in the preconstruction process. It is difficult to confirm with any degree of accuracy, the frequency that these occurrences or causes of duration escalation are rooted in or otherwise could have been mitigated during the preconstruction phase. The author believes that those failures approach 95%.

Other causes described by respondents include the following:

- Contractor failed to install causeway prior to spring stream restriction dates
- There was a major waterline located under the backfill location of one of the wings for the bridge that was essentially along the wall. This pipe failed during construction causing the backfill to washout and major effort was needed to restore/replace
- Late NTP (Notice to Proceed)
- Tall fill was constructed on stone columns and rock fill to prevent settlement but fill settled anyway probably due to plan ambiguity/errors that contributed to inadequate field work and the use of plastic clay as borrow to construct fill
- Railroad Interface/interference
- Physical space limitations

Two of the 4 other causes cited are clearly assignable to the owner traceable to preconstruction.

5.11 Assessment of Key Performance Indicators as Project Input Variables

The effectiveness of certain project input variables or characteristics in the study were measured as key performance indicators (KPI or KPIs) of upstream processes. The KPIs considered in the section are not performance measures of the project itself but of the components that guide or facilitate construction operations. They could be termed project characteristics. The KPI values are not derived from hard outputs but are perceived performance qualities measured as semantic differentials. As described in Chapter 2 addressing research methodology, these KPIs were formulated from responses to specific questions rated on a bipolar scale of 1-7. Semantic differentials are considered continuous data from which descriptive statistics such as mean, median, standard error, standard deviation, confidence levels, etc. can be computed.

The first three are measures of design performance. These include how well the plans and contract documents addressed the constraints present during construction, how accurate and comprehensive the plans and other contract documents were in addressing all contract requirements, and the constructability of the plans and details. The next two are assessments the contractor's planning and scheduling efforts. These include quality and effectiveness of the schedule and the commitment to effective planning and scheduling. The next two are measures of working relationship and team dynamics. One assesses the level of trust between the owner and contractor and the other measures the level of communication among the various sections within the owner's organization.

The subsections that follow address each of these KPIs in terms of mean semantic differential (MSD) and include bar charts with 95% C.I. error bars for on time and late project subsets as well as all projects in the final pool. MSD values for the Bears and

Liger projects subsets are also provided. While the differences between mean semantic differentials for the on time and late subsets do not generally appear to be significantly different statistically, there are clearly observable, measurable differences.

5.11.1 Addressing Constraints

The question in the survey read: *"How adequately were the applicable constraints addressed in the contract documents?"* The question appeared immediately following the listing of constraints. The bipolar adjectives were inadequately and quite adequately, ranging from 1-7. Figure 76 is a bar chart displaying MSD values for on time, late, and projects. The mean semantic differential, MSD, for On Time projects was 5.500 and 4.833 for late projects, with sample standard deviation, s of 1.724 and 1.248, respectively. There is a measurable difference in MSD values between On Time and Late projects where $\Delta_{O\text{-}L}$ equals 0.667. The interpretation of this result is that the MSD of addressing constraints for on time projects is greater than the MSD for late projects. The MSD for Bear projects was 4.071 compared to 5.326 for Liger projects, s = 0.829 and 1.446 respectively. $\Delta_{L\text{-}B} = 1.255$. The MSD for all projects was 5.033, s = 1.426.

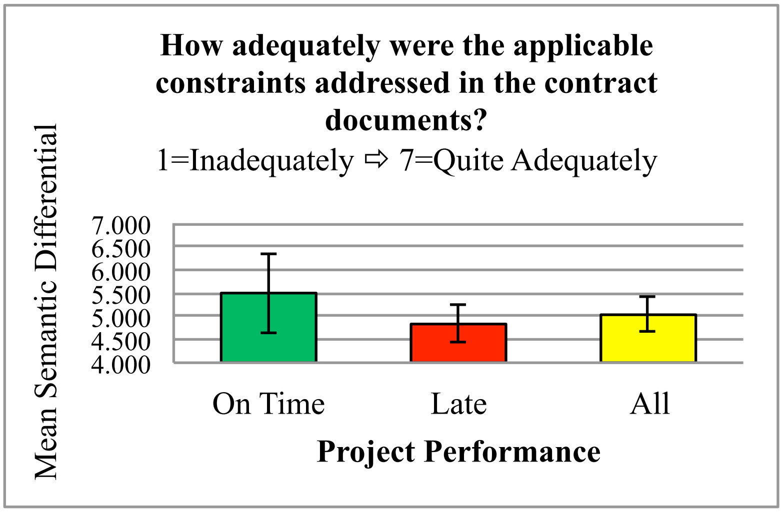


Figure 76 - How adequately were the constraints addressed in the contract documents?

5.11.2 Schedule Quality

The question in the survey read: *Compared to other projects, what was the general quality and effectiveness of the contractor's schedule?* The bipolar adjectives for semantic response were poor and excellent. Figure 77 is a bar chart displaying MSD values for on time, late, and projects. The MSD for on time projects was 5.409 and 4.452 for late projects, s = 0.666 and 1.797 respectively. $\Delta_{O\text{-}L}$ = 0.957 indicates that there is a measurable difference in MSD values between on time and late projects. MSD for Bear projects was 3.867, s = 1.598 and 5.061, s = 1.464 for Liger projects. The MSD for all projects was 4.781, s = 1.568.

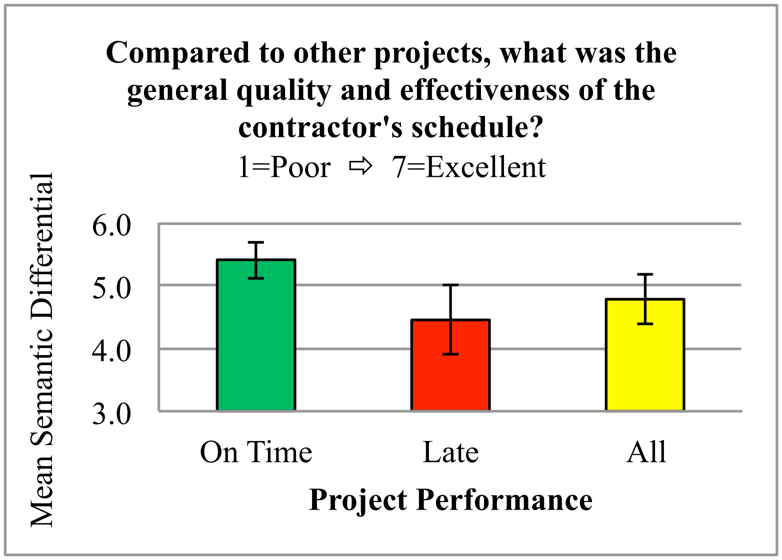


Figure 77 - Compared to other projects, what was the general quality and effectiveness of the contractor's schedule?

Notice that the error bars for on time and late projects in Figure 77 do not overlap. This is an indication that there is a significant difference between the two MSD values. The Mann Whitney test was run to confirm these findings since these MSD values come from subsets that are not likely normally distributed. H_0: the median semantic differentials for the two subsets are the same, H_1: not the same. The test was significant at $p = 0.0348 < 0.05$. Therefore, these two are measurably and significantly different. The interpretation of these results is that the MSD for quality of the schedule is greater for on time projects then the MSD for late projects.

5.11.3 Trust

The question in the survey read: *Compared to a typical project, the working relationship and level of trust between the owner and contractor on this contract was?* The bipolar adjectives for semantic response were much worse and much better. Figure 78 is a bar chart displaying MSD values for On Time, Late, and projects. The MSD for on time projects was 5.364 and 4.786 for late projects, s = 1.093 and 1.523. Δ_{O-L} = 0.578 indicates that there is a measurable difference in MSD values between on time and late projects. Interpretation of this result is that the MSD of trust for on time projects is greater than the MSD for late projects. The MSD for Bear projects was 4.133 and 5.245 for Liger projects, s = 1.125 and 1.392. The MSD for all projects was 4.984, s =1.409.

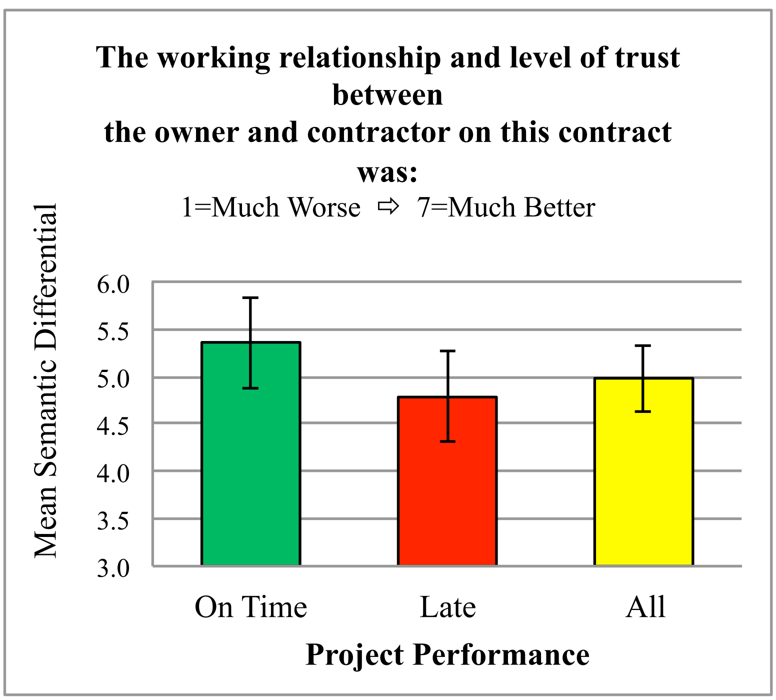


Figure 78 - Level of trust between owner and contractor

5.11.4 Effective Planning

The question in the survey read: *Did the contractor's schedule appear to be produced merely to satisfy a specification requirement or an attempt to provide an effective tool to manage time, resources, and constraints?* The bipolar adjectives for semantic response were requirement satisfaction and effective tool. Figure 79 is a bar chart displaying MSD values for on time, late, and projects. The MSD for on time projects was 4.591 and 4.381 for late projects, s = 1.709 and 1.738. $\Delta_{O\text{-}L}$ = 0.210 indicates that there is a small but measurable difference in MSD values between on time and late projects. Interpretation of this result is that the MSD of effective planning for on time projects is greater than the MSD for late projects. The MSD for Bear projects was 3.933 and 4.612 for Liger projects, s = 1.668 and 1.718. The MSD for all projects was 4.453, s =1.718.

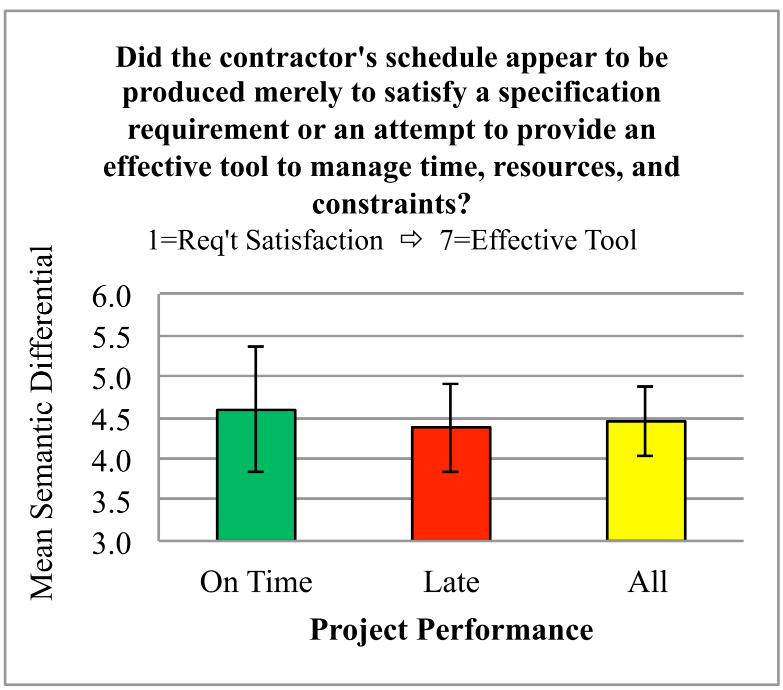


Figure 79 - Was the schedule an effective planning tool?

5.11.5 Accurate, Comprehensive Plans

The question in the survey read: *How comprehensive and accurate were the plans and other contract documents compared to the typical project?* The bipolar adjectives for semantic response were much worse and much better. Figure 80 is a bar chart displaying MSD values for on time, late, and projects. The MSD for on time projects was 4.636 and 4.357 for late projects, s = 1.293 and 1.265. $\Delta_{O\text{-}L}$ = 0.279 indicates that there is a small but measurable difference in MSD values between on time and late projects. Interpretation of this result is that the MSD of accurate, comprehensive plans for on time projects are greater than the MSD for late projects. The MSD for Bear projects was 4.067 and 4.571 for Liger projects, s = 0.961 and 1.339. The MSD for all projects was 4.453, s = 1.275.

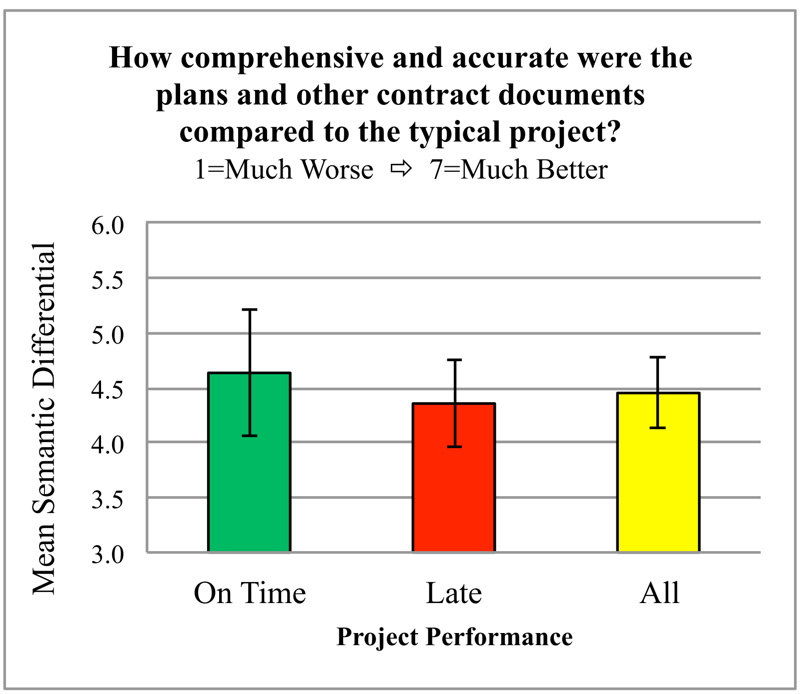


Figure 80 - How comprehensive and accurate were the plans?

5.11.6 Constructability

The question in the survey read: *How constructable were the plans and details for this contract compared to the typical project?* The bipolar adjectives for semantic response were much worse and much better. Figure 81 is a bar chart displaying MSD values for on time, late, and projects. The MSD for on time projects was 4.864 and 4.310 for late projects, s = 0.941 and 1.239. $\Delta_{O\text{-}L}$ = 0.554 indicates that there is a measurable difference in MSD values between on time and late projects. Interpretation of this result is that the MSD of constructability for on time projects is greater than the MSD for late projects. The MSD for Bear projects was 4.000 and 4.653 for Liger projects, s = 0.845 and 1.217. The MSD for all projects was 4.500, s = 1.168.

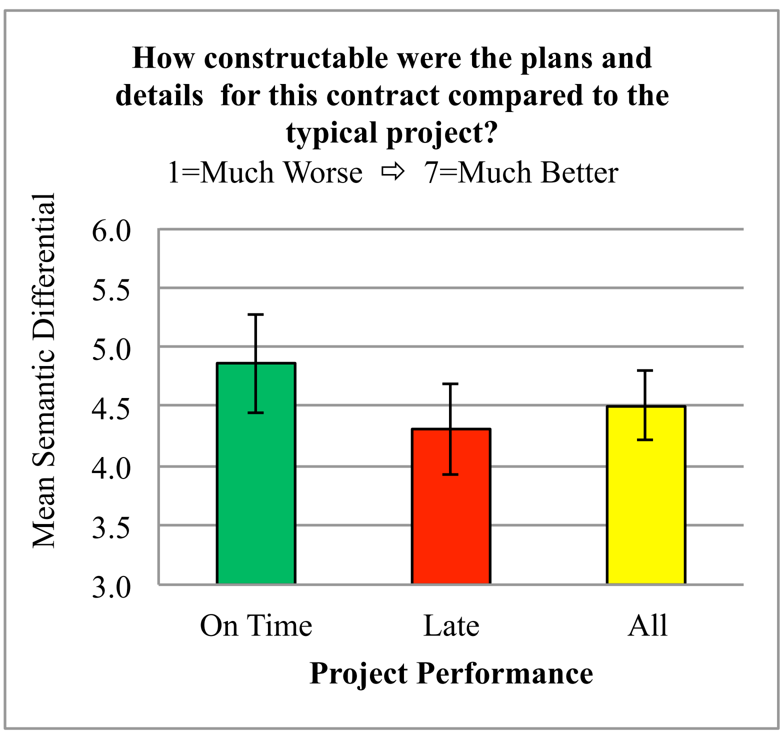


Figure 81 - How constructable were the plans?

5.11.7 Intra-Agency Communication

The question in the survey read: *Compared to other projects, the level of intra-agency communication within the DOT/SHA on this project was?* The bipolar adjectives for semantic response were much worse and much better. Figure 82 is a bar chart displaying MSD values for on time, late, and projects. The MSD for on time projects was 5.095 and 4.951 for late projects, s = 0.995 and 1.161. $\Delta_{O\text{-}L}$ = 0.144 indicates that there is a small but measurable difference in MSD values between on time and late projects. Interpretation of this result is that the MSD of intra-agency communication for on time projects is greater than the MSD for late projects. The MSD for Bear projects was 4.533 and 5.149 for Liger projects, s = 0.915 and 1.122. The MSD for all projects was 5.000, s = 1.101.

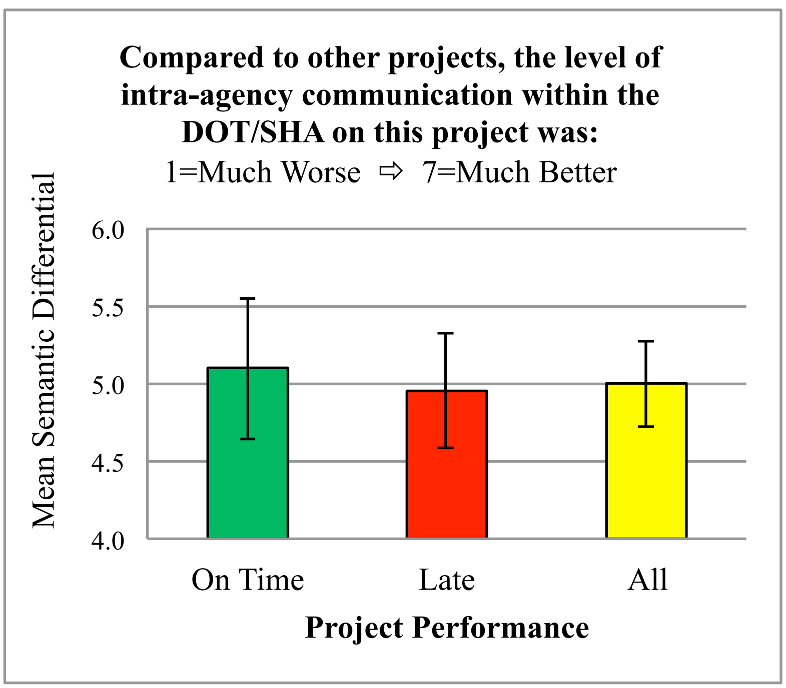


Figure 82 – Chart showing intra-agency communication

5.11.8 Discussion of Mean Semantic Differentials Values for KPI variables

A summary of mean semantic differentials for key performance indicators is found in Table 48. The table includes a listing and comparison of KPI MSD values for the on time and late project subsets and the Bear and Liger subsets. Schedule quality, addressing constraints, trust, and constructability exhibit the largest difference, with $\Delta > 0.5$. Effective planning in the Bear vs. Liger comparison also yields $\Delta > 0.5$. As demonstrated in Section 5.11.2, the MSD of scheduled quality between on time and late project subsets are significantly different.

Table 48 - Summary of mean semantic differentials for key performance indicators

	KPI Mean Semantic Response Differentials MSD Values with Sample Standard Deviation s						
Key Performance Indicators	**All**	On Time	Late	$\Delta_{O\text{-}L}$	Bears	Ligers	$\Delta_{L\text{-}B}$
Addressing Constraints	5.033	5.500	4.833	0.667	4.071	5.326	1.255
	1.426	1.724	1.248		0.829	1.446	
Schedule Quality	4.781	5.409	4.452	0.957	3.867	5.061	1.194
	1.568	0.666	1.797		1.598	1.464	
Trust	4.984	5.364	4.786	0.578	4.133	5.245	1.112
	1.409	1.093	1.523		1.125	1.392	
Effective Planning	4.453	4.591	4.381	0.210	3.933	4.612	0.679
	1.718	1.709	1.738		1.668	1.718	
Accurate, Comprehensive Plans	4.453	4.636	4.357	0.279	4.067	4.571	0.504
	1.272	1.293	1.265		0.961	1.339	
Constructability	4.500	4.864	4.310	0.554	4.000	4.653	0.653
	1.168	0.941	1.239		0.845	1.217	
Intra-Agency Communication	5.000	5.095	4.951	0.144	4.533	5.149	0.616
	1.101	0.995	1.161		0.915	1.122	
Aggregated Means	4.744	5.066	4.581	0.484	4.086	4.945	0.859

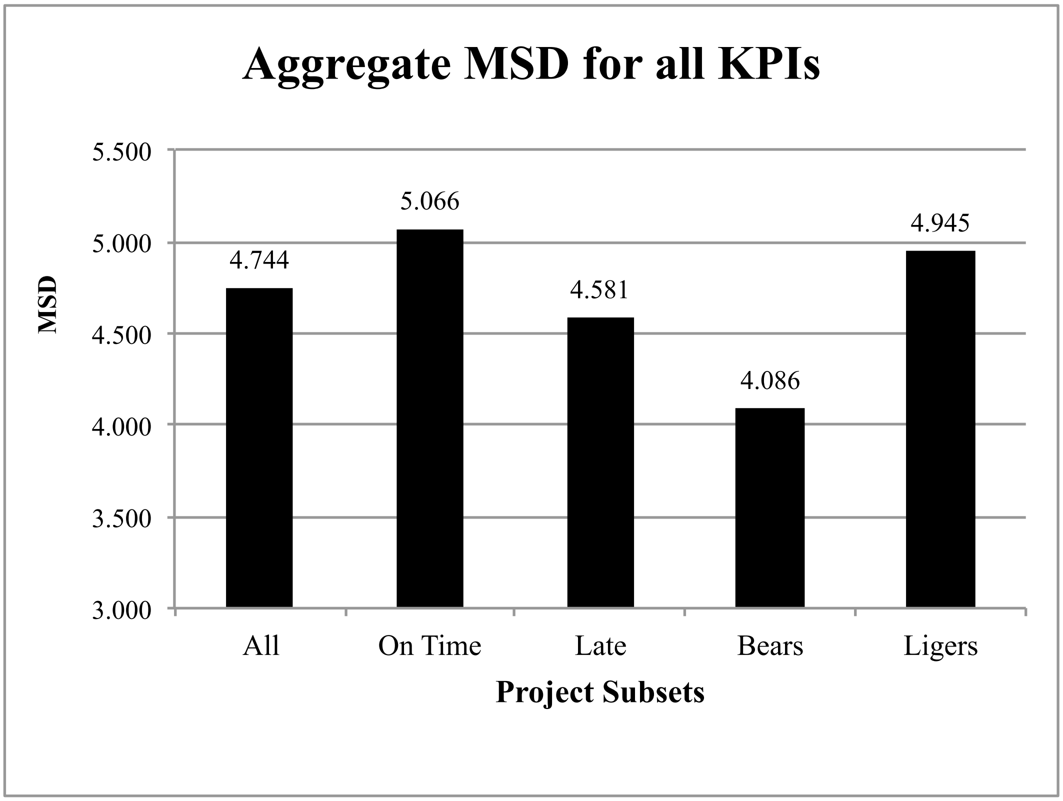


Figure 83– Plot of the Aggregate MSD values for the various Project Subsets

A review of the comparisons between Bear and Liger project subsets revealed that the MSD values of addressing constraints and trust KPIs are significantly different statistically as well. The difference was determined by comparing the 95% CI upper limit (CCUL) for the Bear subset against the 95% CI lower limit (CCLL) for the Liger projects. The CI limits for addressing constraints were Bears = 4.550 and the Ligers CCLL = 4.876. The gap of 0.327 between the Bear CCUL - Liger CCLL indicates a significant difference between the two subsets for the addressing constraints KPI. The CI limits for trust were Bear CCUL = 4.757 and the Liger CCLL = 4.836. The gap of 0.080

between the Bear CCUL - Liger CCLL indicates a significant difference between the two subsets for the trust KPI.

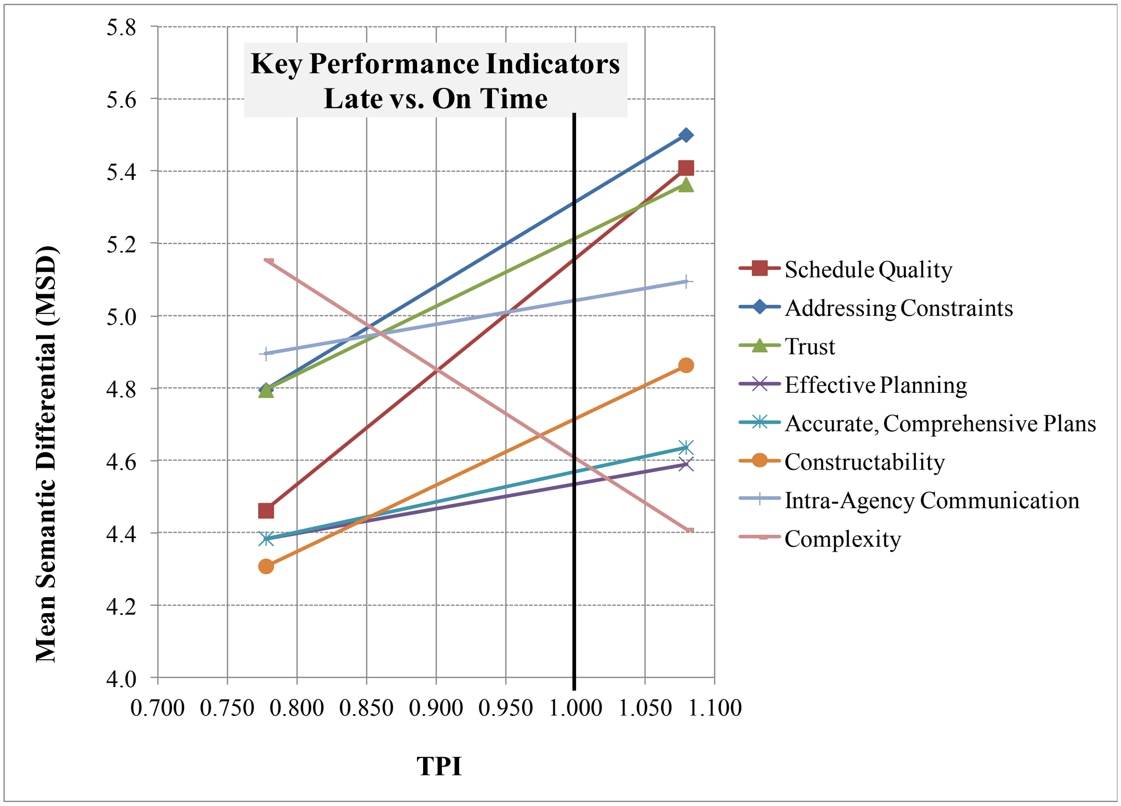


Figure 84 – Plot of MSD values from late and on time projects for the various KPIs

Figure 84 is a plot the MSD values of each KPI for the late and on time subsets. Lines were drawn to connect the late and on time MSD values. The chart provides a visual sense of slope between late and early MSD values. As expected, the lines for schedule quality, addressing constraints, trust, and constructability exhibit the steepest slopes. In all KPI cases, the line is positive or upward sloping indicating a positive relationship between the KPI and TPI. The exception is the line for complexity. Complexity is not a KPI, it is a condition

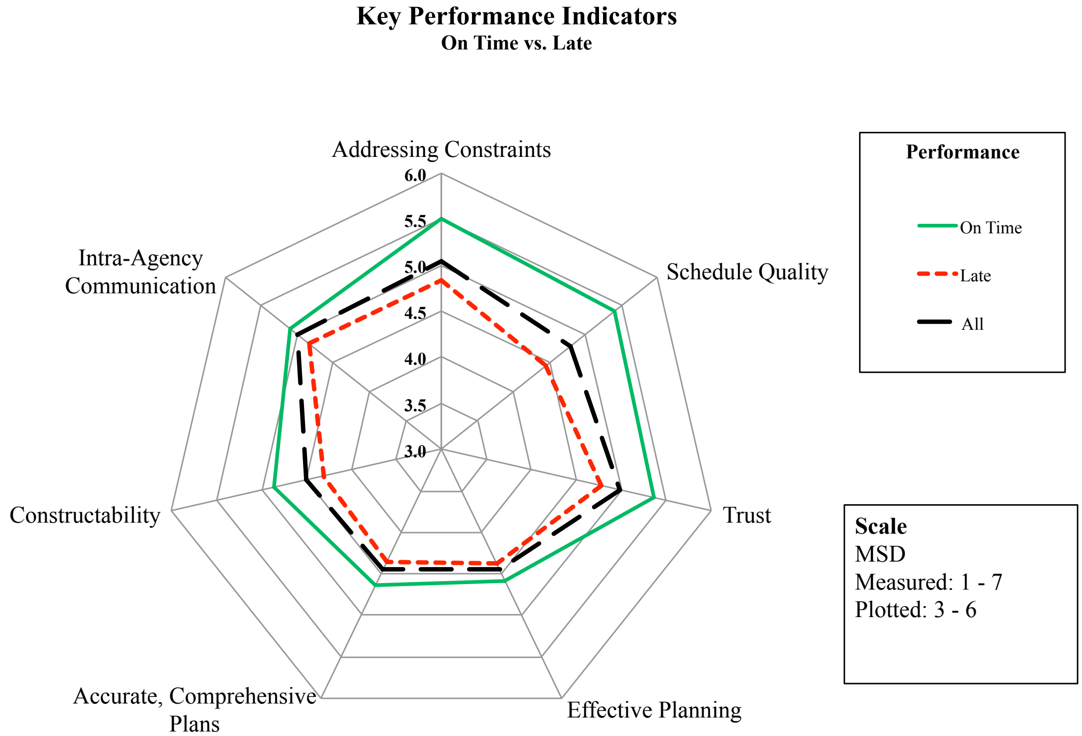


Figure 85 – Radar plot of MSD values of KPIs for Late, On Time, and All Projects

Figures 85 and 86 are radar plots of the MSD values of the associated KPIs. Figure 85 is a plot of Late, On Time, and All Projects. Figure 86 is plot of Bear and Liger subsets as well as All Projects. The Δ values between subsets for each KPI are listed in Table 48. The chart in Figure 84 displays MSD values of the various the KPIs and the subsets' mean TPI values. The radar plots provide a good holistic view of the KPI – mean TPI relationship based on performance or agency subset.

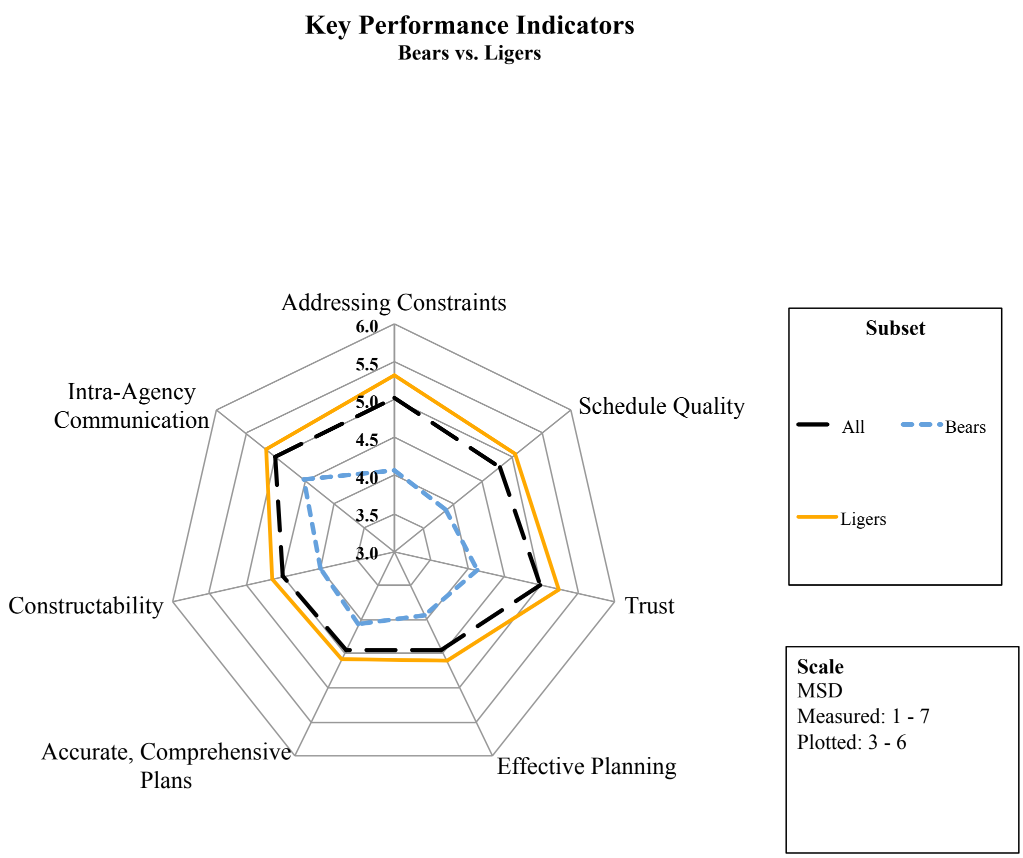


Figure 86- Radar plot of MSD values of KPIs for Bears, Ligers, and All Projects

5.11.9 Correlation Analysis of KPI Semantic Differentials, TPI, and PPI Variables

Correlation analysis was performed using Minitab 16 to compute the Spearman rho (ρ) correlation coefficients for ordinal categories, and resulting p-values for the KPI semantic differentials, TPI and PPI values of All Projects and the subsets of interest. The subsets include On Time, Late, Bear, and Liger projects. The hypothesis of the test is H_0: $\rho = 0$, H_1: $\rho \neq 0$. The test is significant at $p < 0.05$, at which point the null hypothesis is rejected and the two variables are said to be correlated. The author is not inferring causation in highlighting correlation among the TPI, PPI, and KPI variables, merely indicating the existence of a relationship between the two.

Interpretation of the size or strength of correlation is rather subjective and highly dependent upon the nature of the data and the experiment. It is further dependent upon the sample size, n, and the intended use of the results. The author applied Table 49 on Page 334 as a guideline in interpreting the size or strength of correlation for the comparisons made in this study. Social science researchers in determining the strength of correlation use these guidelines or ones very similar. While this research is within the bounds of civil engineering, the nature of the study subject, i.e. highway infrastructure projects, and the metrics used to quantify KPIs is closer to social science. Semantic differentials are subjective and not concrete. Furthermore, projects are social constructs with varying levels of complexity resulting from among other factors; human interaction. As in social science research, the author believes that complicating or confounding factors may be present in this study. Therefore, this liberal scale seems appropriate and is applied in this study.

The following tables are aligned in matrices with TPI, KPIs, and PPI as component variables. There is one table each containing the Spearman correlation coefficient for ordinal data, rho (ρ), and p-values of these paired components for All, On Time, Late, Bear, and Liger project sets. For the sake of clarity, the table cells contain only those pairs that demonstrate moderate or strong correlation where Spearman's rho >.3 and the p-value is less than 0.05. The full, unaltered Minitab outputs are available in the appendix. Strong correlations, those with rho > 0.5 are in bold boxes. A discussion of these correlations and their possible implications and interpretations are presented in the following subsections.

Table 49 - Strength of Spearman rho

Correlation	Abs. Value
None	0 to 0.1
Low	0.1 to 0.3
Moderate	0.3 to 0.5
Strong	0.5 to 0.8
Very Strong	0.8 to 1.0

Table 50 – Correlation matrix of TPI, KPIs and PPI values for ALL Projects

Correlation Matrix for All Projects, Spearman rho, p-value

	TPI	Addressing Constraints	Complexity	Schedule Quality	Trust	Effective Planning	Accurate, Comp. Plans	Construct.	Intra-Agency Comm.
Addressing Constraints									
Complexity									
Schedule Quality									
Trust				0.715					
				0.000					
Effective Planning				0.623	0.591				
				0.000	0.000				
Accurate, Comp. Plans		0.354				0.325			
		0.004				0.015			
Constructability		0.306		0.372	0.353		0.796		
		0.049		0.001	0.000		0.000		
Intra-Agency Comm.		0.350			0.342	0.405	0.387	0.447	
		0.008			0.003	0.007	0.000	0.000	
PPI		0.530					0.359		
		0.000					0.000		

Correlation Matrix for On Time Projects, Spearman rho, p-value									
	TPI	Addressing Constraints	Complexity	Schedule Quality	Trust	Effective Planning	Accurate, Comp. Plans	Construct.	Intra-Agency Comm.
Addressing Constraints									
Complexity									
Schedule Quality			**0.651**						
			0.007						
Trust									
Effective Planning				0.426					
				0.037					
Accurate, Comp. Plans		0.350							
		0.040							
Constructability							**0.806**		
							0.001		
Intra-Agency Comm.		0.324							
		0.006							
PPI		**0.532**							
		0.039							

Table 51 - Correlation matrix of TPI, KPIs, and PPI values for On Time Projects

Correlation Matrix for Late Projects, Spearman rho, p-value									
	TPI	Addressing Constraints	Complexity	Schedule Quality	Trust	Effective Planning	Accurate, Comp. Plans	Construct.	Intra-Agency Comm.
Addressing Constraints									
Complexity									
Schedule Quality			0.373						
			0.000						
Trust		**0.508**	0.327	**0.728**					
		0.000	0.001	**0.000**					
Effective Planning				**0.796**	**0.736**				
				0.000	**0.000**				
Accurate, Comp. Plans					0.325				
					0.001				
Constructability				0.433	0.411	0.326	**0.808**		
				0.000	0.000	0.002	**0.000**		
Intra-Agency Comm.		0.377			**0.578**	0.402	0.467		
		0.014			**0.002**	0.015	0.000		
PPI		0.482	0.433		0.358		0.434		0.400
		0.001	0.016		0.000		0.000		0.000

Table 52 - Correlation matrix of TPI, KPIs, and PPI values for Late Projects

Correlation Matrix for Bear Projects, Spearman rho, p-value

	TPI	Addressing Constraints	Complexity	Schedule Quality	Trust	Effective Planning	Accurate, Comp. Plans	Construct.	Intra-Agency Comm.
Addressing Constraints									
Complexity									
Schedule Quality									
Trust				0.824					
				0.000					
Effective Planning				0.913	0.866				
				0.000	0.000				
Accurate, Comp. Plans		0.444	-0.520		0.338				
		0.041	0.027		0.000				
Constructability			-0.774				0.853		
			0.003				0.000		
Intra-Agency Comm.							0.478		
							0.000		
PPI									

Table 53 - Correlation matrix of TPI, KPIs, and PPI values for Bear Projects

Correlation Matrix for Liger Projects, Spearman rho, p-value

	TPI	Addressing Constraints	Complexity	Schedule Quality	Trust	Effective Planning	Accurate, Comp. Plans	Construct.	Intra-Agency Comm.
Addressing Constraints									
Complexity									
Schedule Quality			0.400						
			0.042						
Trust				0.587					
				0.000					
Effective Planning				0.575	0.459				
				0.000	0.001				
Accurate, Comp. Plans									
Constructability			0.374	0.342		0.362	0.801		
			0.024	0.004		0.003	0.000		
Intra-Agency Comm.		0.341			0.388	0.477		0.369	
		0.032			0.002	0.002		0.001	
PPI		0.336	-0.317						
		0.001	0.033						

Table 54 - Correlation matrix of TPI, KPIs, and PPI values for Liger Projects

5.11.9.1 Summary of Observed Correlations

The maximum potential number of pairs is determined by k(k-1)/2, where k = number of variables. In the correlation analyses performed under this section of the study, there were 2 dependent variables, specifically TPI and PPI, and 8 independent variables, namely the 7 KPIs, and one condition, complexity. Therefore n = 10. The total number of pairs is 10(10-1)/2 = 45. Since there are 5 subsets, there is the potential to observe 225 correlated pairs. There were a total of 81 observed correlations across the 5 subsets. This translates into 36% of all pairs exhibiting some level of correlation.

Identification of the pairs was facilitated through use of the abbreviations listed in Table 55. The convention used to identify the pairs was the column variable/row variable, e.g. “SQ” from the column/”T” from the row; simply SQ/T.

Table 55 – List of abbreviations for variables

Abbreviations	
Addressing Constraints	AC
Complexity	X
Schedule Quality	SQ
Trust	T
Effective Planning	EP
Accurate, Comp. Plans	AP
Constructability	C
Intra-Agency Comm.	IAC

Table 56 - Strongly or very strongly correlated pairs

Pairs Exhibiting Strong Spearman Correlation							
Pairs	**All**	**On Time**	**Late**	**Bears**	**Ligers**	**Count**	**Mean ρ**
AC/PPI	0.530	0.532				2	0.531
AC/T			0.508			1	0.508
AP/C	0.796	0.806	0.853	0.853	0.801	5	0.822
SQ/EP	0.623		0.796	0.913	0.575	4	0.727
SQ/T	0.715		0.728	0.824	0.587	4	0.714
T/EP	0.591		0.736	0.866		3	0.731
T/IAC			0.578	-0.520		2	0.549
X/AP				-0.774		1	0.774
X/SQ		0.651				1	0.651
Count c	5	3	6	6	3	23	0.667

Of the total 45 pairs, 33 or 73.3% exhibited some level of correlation in at least one subset. Three of these including AC/AP, SQ/EP, and T/EP exhibited correlation for all 5 subsets. Correlation was observed in 5 pairs including AC/IAC, AC/PPI, SQ/T, AP/C, and AP/PPI in 4 subsets. Eight correlated pairs were found in 3 subsets. These included SQ/C, T/AP, T/C, T/IAC, EF/AP, EF/C, EF/IAC, and AP/IAC. Twenty-three (23) pairs exhibited strong correlations in at least one subset. Table 56 lists the pairs exhibiting strong correlation.

Of the pairs listed in Table 56, AP/C was present in 5 subsets and SQ/EP and SQ/T were present in 4 subsets. T/EP was present in 3 subsets and AP/PPI and T/IAC each in 2 subsets. The Late and Bear project subsets had the largest frequency of strongly correlated pairs with 6 observations each.

5.11.9.2 Correlations – All Projects

There were a total of 20 pairs reflecting some degree of positive correlation found in the analysis of All Projects. Of these, 5 were strong correlations and 11 were moderate. The pairs, which exhibited strong correlation, include SQ/T, SQ/EP, T/EP, AP/C, and AC/PPI. The correlations between schedule quality and effective planning was $\rho = 0.623$. The correlation between schedule quality and trust was $\rho = 0.715$ and between trust and effective planning was $\rho = 0.591$. There correlation between constructability and accurate plans was $\rho = 0.796$ and between addressing constraints and PPI was $\rho = 0.530$.

5.11.9.3 Correlations – On Time Projects

There were a total of 8 correlated pairs observed for the On Time Projects subset, including 3 that exhibited strong correlation. These included AC/PPI, X/SQ, and AP/C. The correlation between addressing constraints and PPI was $\rho = 0.532$. The correlation between complexity and schedule quality was $\rho = 0.651$. The correlation between accurate, comprehensive plans and constructability was $r = 0.806$.

5.11.9.4 Correlations – Late Projects

There were a total of 27 correlated pairs observed for the Late Projects subset, including 6 pairs exhibiting strong correlation. These included AC/T, SQ/T, SQ/EP, T/EP, AP/C, and T/IAC. The correlation between addressing constraints and trust was $\rho =0.508$. The correlation between schedule quality and trust was $\rho = 0.728$ and $\rho = 0.578$ between trust and intra-agency communication, and ρ = 0.736 for the correlation between trust and effective planning. The correlation for accurate, comprehensive plans with constructability was ρ = 0.853.

5.11.9.5 Correlations – Bear Projects

There were 9 correlated pairs observed for the Bear Project subset. Six (6) of these pairs exhibited strong correlation, including AP/C, SQ/EP, SQ/T, T/EP, T/IAC, and X/AP. The correlation between accurate, comprehensive plans and constructability was ρ = 0.853. The correlation between schedule quality and effective planning was ρ = 0.913. The correlation between schedule quality and trust was ρ = 0.824. The correlation between trust and effective planning was ρ = 0.866 and between trust and intra-agency communication ρ = -0.520. Trust is in 3 of the strongly correlated pairs. Finally, the correlation between complexity and accurate, comprehensive plans was ρ = -0.774

5.11.9.6 Correlations – Liger Projects

Fourteen (14) correlated pairs were observed for the Liger Projects subset, including 3 that exhibited strong correlation. Those exhibiting strong correlation included SQ/T, SQ/EP, and AP/C. The correlation between schedule quality and trust was ρ = 0.587. The correlation between schedule quality with effective planning was ρ = 0.575. The correlation between accurate, comprehensive plans and constructability was ρ = 0.801.

5.11.9.7 Correlations – Closing Discussion

Spearman's Rank Correlation Coefficient is a nonparametric measure of statistical dependence between two variables. Identifying correlations does not prove causation. It does however; demonstrate association and the possible existence of a relationship between two variables. The strong correlations that occurred most frequently are highlighted in Table 56 on Page 338. Some of these correlations such as the relationship between schedule quality and effective planning are expected. The relationship is not surprising since the latter is believed to be required for the former. The relationship between accurate, comprehensive plans and constructability are no surprise either. The fact that accurate plans are related to PPI may indicate that there is some association between contract documents and price performance. The author believes that accuracy and completeness of the plans is an explanatory input variable, which has some role in determining PPI. What may seem surprising is the effect of trust on schedule quality and effective planning. The author speculates that this is two-way for both relationships, in that trust fosters effective planning and schedule quality and vice versa. It is possible that the semantic differentials for these 3 variables rise and drop as a function of overall project dynamics or that there are other confounding variables at play. There are not sufficient data to prove or disprove any of these possibilities. However, the frequency of occurrence and the strong correlations clearly indicate the importance of the variable, trust. Figure 87 is a chart displaying the frequency of occurrence of the strongly or very strongly correlated variables. As shown on the chart in Figure 87, trust has the highest frequency of all strongly correlated variables with 10 occurrences. The influence of trust on project performance and timely delivery cannot be ignored.

The chart does not include TPI or PPI values that were included in the correlation analysis since they are dependent output variables. The frequency for PPI was 16 and only 3 for TPI.

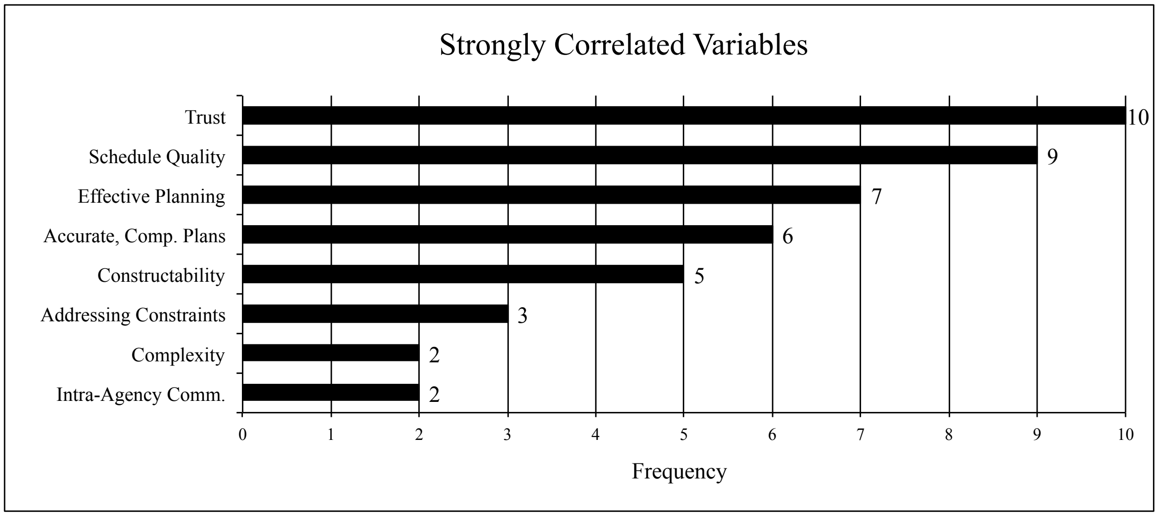


Figure 87 - Chart displaying frequency of strongly or very strongly correlated variables. Note that TPI and PPI values are not included in this chart

The importance of accurate and comprehensive plans is well understood across the entire architectural, engineering, and construction (AEC) community. It is difficult from the data to quantify influence, which accurate, complete contract documents, or the lack thereof has in timely completion. Excluding utility impacts, failures in the contract documents/preconstruction engineering are directly responsible for at least 55% of the occurrences of duration escalation. The author suggests that a substantially greater percentage of duration escalation can be traced back to the contract plans and specifications. There is insufficient data to prove or disprove that assertion. However, the data does indicate that accurate, comprehensive plans are important factors in successful, timely highway project delivery.

5.12 Complexity

Complexity is a rather nebulous term with different meanings and in different contexts. As noted in the discussion Chapter 2, it was important to define complexity within the context of highway project delivery. The author prepared a declarative statement that was validated by 95% of the respondents to single question posed to 50 seasoned bridge and highway engineers. Of the 50 that were polled, 39 responded, yielding a 78% response rate. The average experience level was 33 years. Thirty-seven (37) out of the 39 respondents confirmed that the following statement was a valid and appropriate definition of complexity in highway project delivery. This statement precedes the question on comparative complexity in the survey questionnaire.

> *"Complexity in highway project construction is a function of: 1) the number and level of physical constraints, i.e.: space, traffic, utilities, wetlands, waterways, railroads, etc.; 2) interdependencies among activities and/or resources; 3) staging (sequence) or phasing of work; 4) contractual and/or other legal constraints; 5) socio-political influence; 6) complexity of details; 7) degree to which work is not linear or repetitive; 8) uncertainty requiring adaptability. Moreover, an increase in the level of complexity requires a corresponding increase in the intensity of management effort to ensure successful project outcomes."*

The survey question read *"Given the stated criteria, how complex was this project in comparison to the typical project?"* with 1 being Not Very and 7 being Very complex. Figure 88 is a bar chart plotting of the MSD of comparative complexity for On Time, Late, and All Projects. The MSD for On Time Projects was 4.409 and 5.154 for Late Projects with s =1.843 and 1.368, respectively. The $\Delta_{O\text{-}L}$ = -0.745. The fact that Δ is negative is demonstrated by its downward sloping line for complexity on the chart in

Figure 84 on Page 330. The MSD for All Projects was 4.828, with s = 1.576. The MSD for Bear Projects was 4.533, s = 1.767 and 5.021, s = 1.511 for Liger projects with Δ_{L-B} = 0.488.

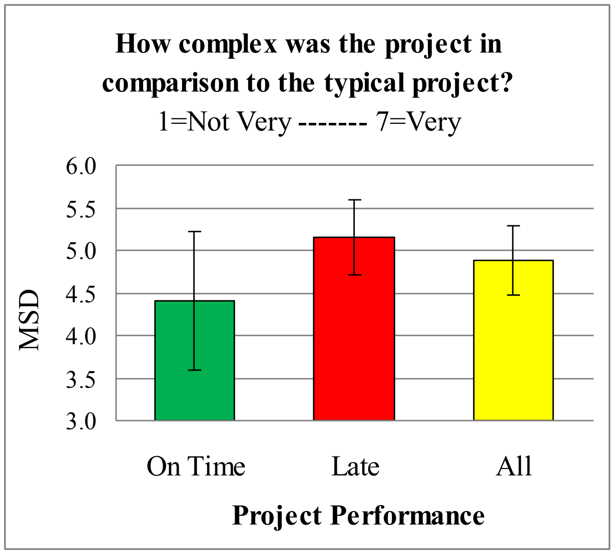


Figure 88 - Chart showing MSD of Complexity for On Time, Late, and All Projects

While not quite statistically significant, there is a clear measurable difference between the MSD values for On Time and Late Projects. Table 57 lists MSD of complexity for various factor including categorical data, constraints, and performance.

Table 57 - MSD of Complexity for various factors. $\Delta_{C\text{-}All}$ = MSD Complexity – MSD All Projects (MSD_{All} = 4.828)

Factor	Complexity MSD	Std. Dev.	$\Delta_{C\text{-}All}$	Factor	Complexity MSD	Std. Dev.	$\Delta_{C\text{-}All}$
New	4.692	1.569	-0.136	Design-Build	3.000	1.000	-1.828
Reconstruction	4.921	1.600	0.093	In-house Design	4.588	1.873	-0.240
Road work only	4.250	1.653	-0.578	Consultant Design	5.047	1.430	0.219
Roads w/bridges	5.250	1.351	0.422	Design-Builder	3.000	1.000	-1.828
Bridges only	4.700	1.720	-0.128	Consultant CM/Insp	4.600	1.838	-0.228
Urban	5.500	1.249	0.672	Owner CM/Insp	4.381	1.596	-0.447
Suburban	4.727	1.579	-0.101	Owner-led CM/Insp	5.182	1.446	0.354
Rural	4.417	1.692	-0.411	Precasting	4.417	1.640	-0.411
Primary Arterial	5.250	1.437	0.422	Off-site Prefab	5.143	1.676	0.315
Minor Arterial	5.200	1.082	0.372	On-site Prefab	4.500	3.536	-0.328
Collector	3.500	1.309	-1.328	Wetlands	5.080	1.498	0.252
Local Road	3.889	2.088	-0.939	Physical Space	5.440	1.530	0.612
Increase Capacity	4.870	1.546	0.042	Streams/waterways	5.167	1.404	0.339
Maintain Function	5.350	1.387	0.522	Phased MOT	5.162	1.344	0.334
Structure Upgrade	4.417	1.832	-0.411	Utilities	5.083	1.482	0.255
Safety Improvement	3.875	1.458	-0.953	Railroad	5.769	0.927	0.941
$2-4 Million	3.909	1.477	-0.919	Owner req't design chg.	5.375	1.408	0.547
$5-20 Million	4.958	1.601	0.130	Errors and omissions	4.111	1.453	-0.717
$21-35 Million	5.750	1.035	0.922	Differing site conditions	5.313	1.138	0.485
>$35 Million	5.800	1.033	0.972	Poor constructability	3.750	2.062	-1.078
Design-Bid-Build	4.918	1.552	0.090	Poor contractor performance	4.286	1.890	-0.542

5.13 Project Priorities – Cost, Quality, and Time

A well-known and accepted standard of evaluating project outcomes is often referred to as the triple constraints of project management. The concept is represented as a triangle with time cost, and quality[88]. In this model, the constraints are competing and in theory, one cannot be elevated in priority without sacrificing one or both of the others. The survey questionnaire asked respondents to rank the triple constraints in priority order for the project in question. The survey questionnaire included a question intended to gauge

[88] Scope is often substituted in place of quality, placing quality in the center of the triangle. Other models use time, cost, and performance where the latter embodies scope, quality, and function.

attitudes towards project priorities. The request read: Rank the importance of project outcomes in terms of the triple constraints of cost, quality, and time with one being the highest priority and 3 being the lowest. The mean, sample standard deviation, and 95% CI values are shown on tables included in the appendix for All Projects and the On Time and Late subsets.

Figure 89 is a plot of the results shown for On Time, Late, and All Projects. Final rankings 1, 2, and 3, were computed and subtracted from 3 to present an inverted plot that is more visually intuitive. Plotted in this manner, the higher priorities are reflected in the larger bars. The bars include 95% CI error bars, which graphically indicate that there is a statistically significant difference among the rankings for the final pool of All Projects.

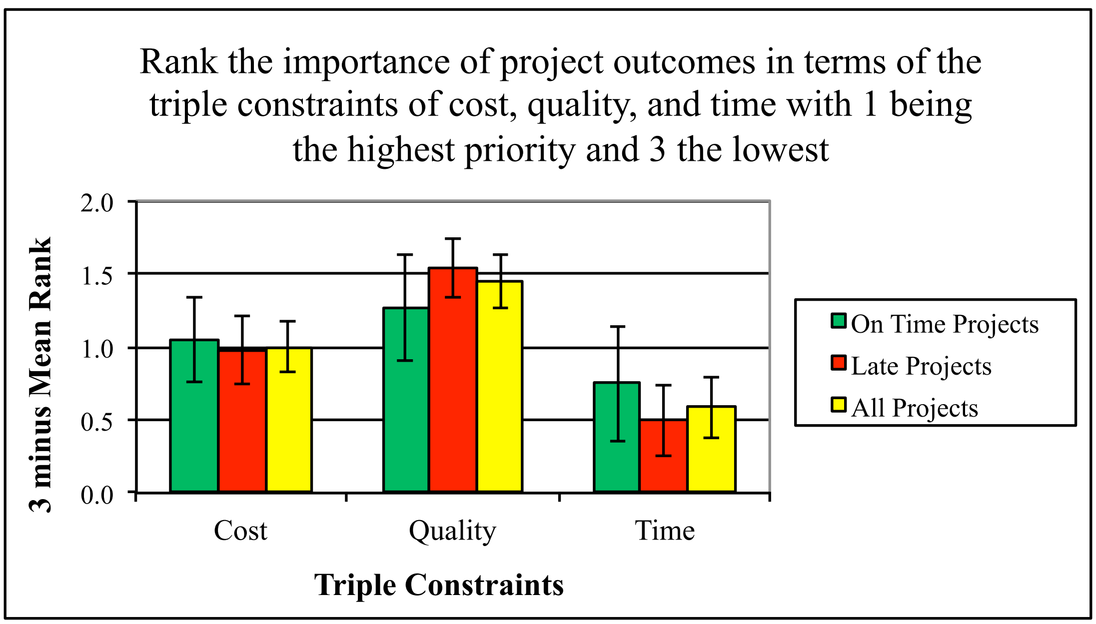


Figure 89 - Attitude toward priorities in the triple constraints

There is clearly a significant difference in the rankings between time and quality for the Late Projects subset. The difference between time and cost is less discernable graphically. Therefore, further testing of these two rankings from the Late Projects subset was conducted to analyze the difference. The individual rankings were first tested for normality. Both tests resulted in $p<0.05$, requiring that H_0 stating normality must be rejected. The cost and time rankings were then tested for homogeneity of variance. The Levene test statistic was 0.05 and $p = 0.951$. The null hypothesis is that two variances are equal, significant at $p<0.05$. Therefore, H_0 was not rejected and the variances are considered equal. Since the rankings are not normally distributed but do have equal variances, the appropriate procedure is the Mann Whitney non-parametric test.

The Mann-Whitney test hypothesis is that the medians of the two groups are equal. The test is significant at $p<0.05$. H_0 is rejected since $p = 0.041$, which is less than 0.05. Therefore, the cost and time rankings from the Late Project subset are **not** equal.

Figure 90 is a line plot of the project priorities in terms of the triple constraints. The plot is a graphical depiction of the attitude of the owners toward project priorities. As demonstrated, the rankings are significantly different and the priorities preferences are very clear. Quality is the highest priority preference followed by cost. Time is the lowest priority in all project subsets.

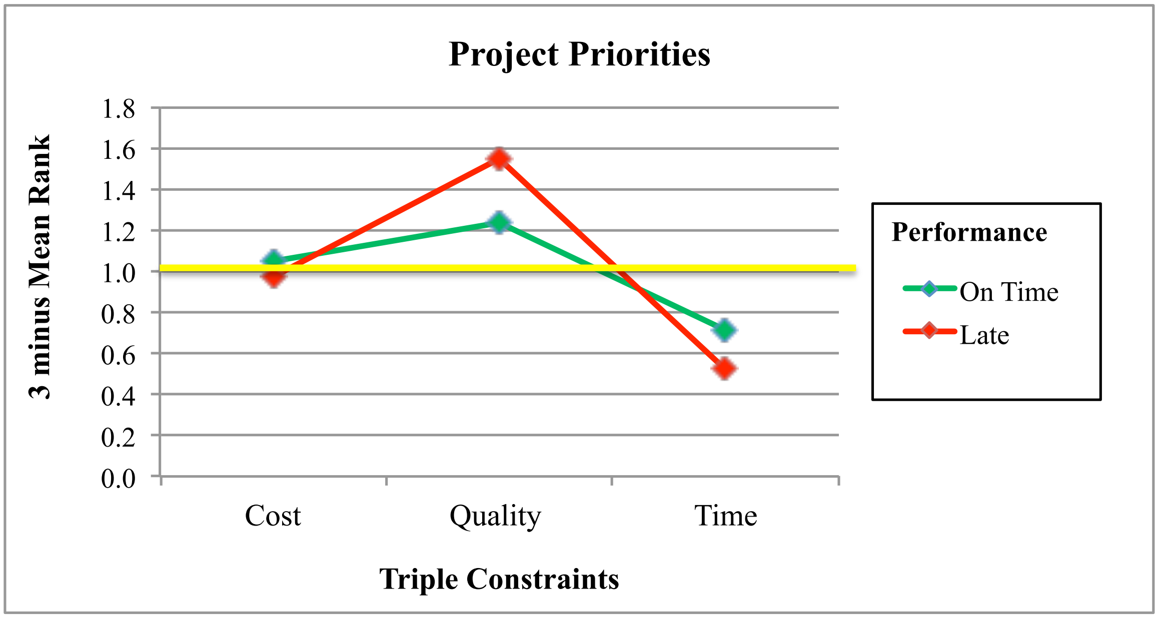


Figure 90 - Three-point attitude plot of priority preferences

5.14 Analysis of Original Contract Duration (OCD)

The final section in this chapter addresses the original contract durations establish by the owner and accepted by the contractor. The HPP Study sought to determine if the original contract durations were achievable. The survey questionnaire included three questions to gauge the viability of the original contract duration. The first question asked: *Based on the original scope of work* ***without*** *considering the effect of weather, was the original contract duration reasonable and achievable?* The choices were a discrete yes or no. Of the 43 projects that finished beyond the original contract duration, or FCD > OCD, 36 respondents answered the question. Of those, 33 selected "yes" and 3 indicated "no". This translates into 91.7% of the respondents for 82.5% of the Late Projects subset confirms that the OCD was reasonable and achievable.

The compliment of this finding was that 8.3% of the respondents representing 7.5% of the Late Projects subset did not believe the OCD was reasonable and achievable. The unconfirmed speculation is that the 4 abstentions represent respondents who either had a neutral opinion or were unsure. This means that 55 of 58 or 94.8% of the responses were affirmative. The interpretation of these findings is that the original contract durations were achievable and reasonable for 95% of the projects in the final pool and that duration escalation occurred as a result of exposure to risk events that were not effectively mitigated.

The second question asked *How ambitious was the original construction contract duration?* The semantic differential scale bipolar adjectives were 1 = Not Very → 7 = Very. Table 58 includes the statistics and Figure 91 is a chart of the MSD responses to the question plotted for On Time, Late, and All Projects. The $\Delta_{O\text{-}L}$ was 0.179 indicating a small measurable difference between the On Time and Late project subsets. The MSD for the two subsets are not significantly different. Oddly, the MSD was greater for On Time project than the MSD for Late projects. This result seems counter-intuitive. One might expect that a contributing factor to duration escalation could be that the OCD was too ambitious to begin with. However, there interpretation of these results is that there is essentially no difference between the On Time and Late projects in this regard and original contract durations were typically not overly ambitious for the projects within this study.

Table 58 - Statistics for MSD response to *How ambitious was the OCD?*

Condition or Attribute	How ambitious was the original construction contract duration?		
Data	**On Time**	**Late**	**All**
Mean Semantic Differential	4.545	4.366	4.429
Sample Standard Deviation	1.438	1.655	1.573
Interval Half Width	0.638	0.522	0.396

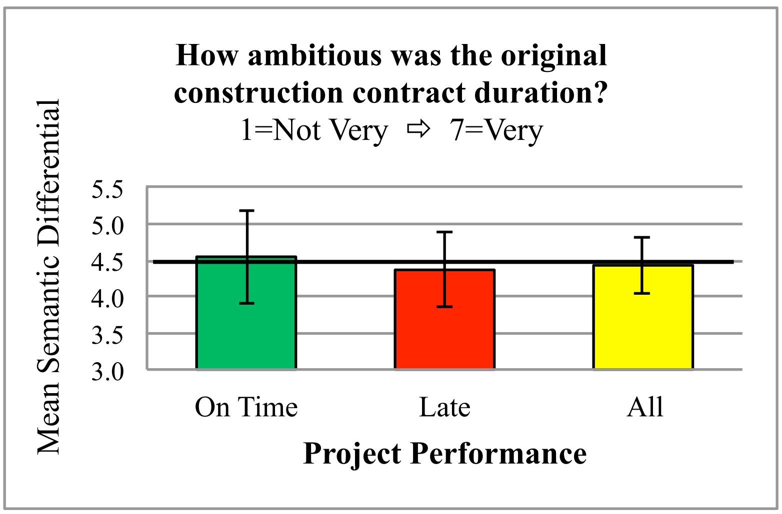


Figure 91 – Plot of MSD response to *How ambitious was the OCD* for On Time, Late, and All Projects

The third question was posed to respondents that indicated completion beyond the OCD. The respondents were asked to: Please answer the following question if the final project duration exceeded the original contract duration.

If not for the stated occurrences/situations, what is the likelihood that the contractor would have finished the project within the original contract duration?

The semantic differential scale bipolar adjectives were 1 = Not Very → 7 = Very. The 38 respondents represent the Late Projects subset only. The MSD was 5.725 with s = 1.601. The MSD value for this question was larger than all other MSD responses received from the Late Projects subset respondent. This relationship is depicted in Figure 92.

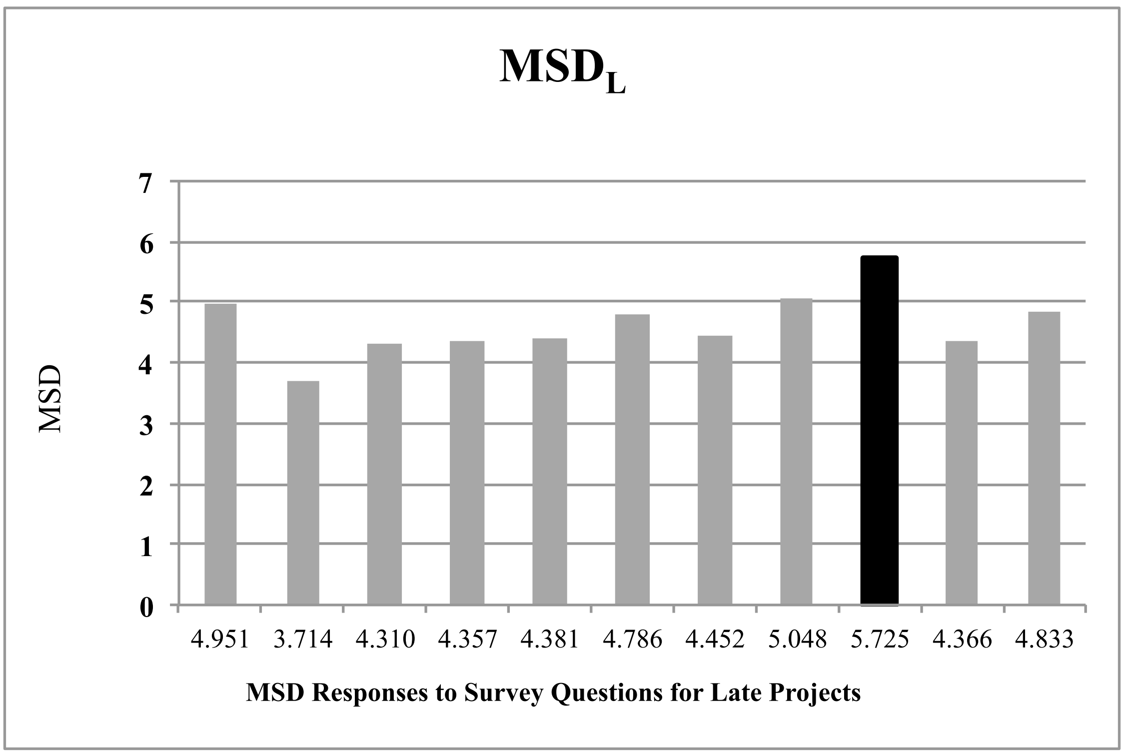


Figure 92 - Chart showing all MSD response values from the Late Projects subset

The mean of all MSD_L for responses within the Late Projects subset was 4.581. The MSD of the response to the likelihood question was 1.261 greater than the mean

MSD_L. The semantic scale is considered continuous to facilitate statistical analysis, but "4" is deemed neutral in attitude. The interpretation is that the response to this question is relatively strong in the affirmative. The summary interpretation of the collective responses to these three questions is that in general the OCD is reasonable and achievable. Duration escalation experienced on projects within this study was caused by events or conditions other than overly optimistic or unrealistic original contract durations.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary Overview

The first chapter of this thesis provided introduction to problem of duration escalation in highway infrastructure delivery, specifically the construction phase. It described the public demand for timely delivery of highway infrastructure. Chapter 1 also contained the literature review, which included findings from previous studies of time performance in highway construction. Chapter 2 described the research methodology for the HPP Study and provided a detail explanation of the survey questions and the underlying rationale. Chapters 3 and 4 provided background information necessary to understand common practices including methodologies, processes, and philosophies prevalent in the industry. Chapter 3 addressed contemporary planning and scheduling practices and other project management techniques and Chapter 4 covered highway project delivery. Chapter 5 presented the results of the HPP Study survey.

Previous studies revealed varying percentages of time growth and provided a listing of causes. The causes listed were based on opinion surveys of owners and contactors. The HPP Study included these causes in the survey. However, rather than anecdotal responses used in the previous study, the HPP Study obtained project-specific data. The information gathered in this study included categorical data as well as those addressing conditions, practices, and constraints believed to increase the risk of duration escalation. This study also gauged input variables from upstream processes as well as ongoing project dynamics and conditions. The inputs from upstream processes and project dynamics are considered KPIs of those efforts. These variables along with the condition of complexity were measured using a semantic differential scale that facilitated comparative analysis among different groups and factors. The results presented in Chapter 5 are summarized here in Chapter 6.

Previous studies refer to time growth in terms of delays and quantify the variances in days or percentages of original contract value. The term *delay* implies occurrence of a specific event or events. The author does not suggest that this term is not valid, however, prefers the term *duration escalation*. The author believes that time growth can and does occur through forces not necessarily defined by a single event or occurrence. Primary causes of delay can be identified and responsibility assigned. One previous study sought to ascertain the root causes of delay and identify behaviors and other underlying factors (Thomas and Ellis, 2001). The root causes suggested by the study were identified through interviews and brainstorming sessions. The author does not discount these findings, but questions whether they are in fact root causes or merely symptoms of a deeper state. It does not appear from the literature that true root cause analysis techniques such as those applied in Lean problem solving were used in the cited study.

This study attempted to identify the factors that influenced duration escalation and quantify relationships among the various input and dependent variables. The Time Performance Index or Indicator, TPI, served as the dependent output variable for this purpose. TPI used within the context of this study was defined as the original contract duration divided by the final contract duration or OCD/FCD. The TPI used here is similar to the efficiency metric used in Earned Value Analysis (EVA), which is the scheduled time divided by the actual time, and reflects performance observed to a point or data date. The actual time used in the denominator of the TPI in this study is the final contract duration.

The TPI demonstrated efficacy in providing a baseline for comparison of various factors considered in this study. TPI in any context should not be confused with the familiar EVA metric, Schedule Performance Index or SPI. SPI is derived using cost-loaded variables and TPI is strictly derived from units of time. TPI does not appear in the literature assessing performance of highway infrastructure projects so its application is unique to this study.

This chapter is organized into 5 additional sections. The first of these summarizes the findings from the HPP Study presented in the previous chapter. The second provides direct responses to the proposed research questions and the third suggests interventions. This is followed by a brief discussion on implementation strategy. The last section suggests areas for continued investigation of the current state and development of models that can be applied to both research and practice.

6.2 Findings from the Highway Project Performance Study

The findings disclosed in the previous chapter are summarized here. This includes coverage of categories, constraints, conditions and outcomes. Where appropriate the section summarizes the TPI against MSD, assesses OR and RR, and compares performance of the On Time, Late, Bear, and Liger. Table 59 is a listing of TPI Values for various factors related categorical classifications for the above mentioned project subsets and includes computed values for $\Delta_{L\text{-}B}$.

Table 59 - List of TPI Values for various factors on Bear, Liger, and All Projects

Factor	Mean TPI			Δ_{L-B}
	All	Bears	Ligers	
New	0.888	0.873	0.889	0.016
Reconstruction	0.840	0.748	0.886	0.138
Road Work	0.862	0.859	0.865	0.005
Roads w/Bridges	0.854	0.757	0.874	0.117
Bridges	0.854	0.556	0.918	0.363
Urban	0.800	0.663	0.868	0.205
Suburban	0.893	0.820	0.927	0.107
Rural	0.871	0.873	0.871	-0.002
Primary Arterial	0.805	0.744	0.833	0.089
Minor Arterial	0.884	0.502	0.910	0.407
Collector	0.879	0.850	0.889	0.038
Local Road	0.987	0.910	1.008	0.098
Increase Capacity	0.905	0.866	0.918	0.052
Upgrade Structure	0.929		0.929	N/A
Restore Function	0.750	0.587	0.815	0.229
Safety Improvement	0.901	0.917	0.892	-0.025
2-4 Million	0.903	0.865	0.918	0.053
5-20 Million	0.804	0.667	0.873	0.205
21-35 Million	0.982		0.982	N/A
>35 Million	0.804	0.938	0.787	-0.151
Consultant CM/Insp Services	0.732	0.720	0.762	0.042
Owner CM/Insp Services	0.979	0.926	0.981	0.055
Owner Lead CM/Insp Services	0.822	0.786	0.832	0.046
DBB	0.860	0.764	0.886	0.122
DB	0.904		0.904	N/A
In-house	0.937	0.819	0.952	0.133
Consultant	0.875	0.756	0.855	0.099

6.2.1 Project Outcomes

Results of the HPP Study indicate that 66.15% all projects in the final pool finished beyond the original contract duration with a mean TPI of 0.859. TPI values across the final pool of all projects ranged from 0.256 to 1.348. Analysis of the results revealed a substantial difference in performance between the Bear and Liger projects. Thirteen (13) out of 15 or 86.7% Bear projects were completed beyond the original contract duration with a mean TPI = 0.764. This was substantially lower than all other Liger projects. Of the 50 Liger Projects, 30 or 60% were completed beyond the OCD with a mean TPI of 0.887. As noted, Table 59 provides a listing of the TPI values on a categorical basis for Bear, Liger, and All projects. Note that in all comparisons, Bear projects exhibit lower TPI values except for projects valued over $35 million. There was however, only 1 Bear project in that category.

A similar study of highway work completed between 2001 and 2005 involving 20 states showed that 47% of all projects finished beyond the OCD. However, of projects in that study valued over $5 million, 65% finished beyond the OCD (Crossett and Hines, 2007). Of the 43 projects valued over $5 million in the HPP Study, 31 or 72% finished beyond the OCD exhibiting a mean TPI = 0.836. HPP Study projects valued at <$5 million included 12 or 54.5% of the 22 finishing beyond the original contract duration. The mean TPI for projects >$5 million was 0.903.

While time performance is the central theme and focus of this thesis, cost should not be ignored. Results show that 65% of all HPP Study projects reporting final contract values (FCV) finished beyond the OCD. Of those finishing over the original contract value (OCV), 16 or 41% finished on time. That is PPI <1 when TPI ≥1. Of those finishing beyond the OCD, 15 or 37.5% were completed on or under the OCV. Figure 93 shows a scatter plot of TPI against PPI. The plot shows a weak positive relationship where $R^2 = 0.0847$. Correlation and regression analysis did not reveal any significant or describable relationship between PPI and TPI or TPI and $ value. Figure 94 is a plot of TPI against the natural log of the contract dollar value. The trendline for the plot shows a negative relationship with a very weak fit Analysis did reveal strong correlation between PPI and accurate, comprehensive plans for All Projects and the On Time projects subset.

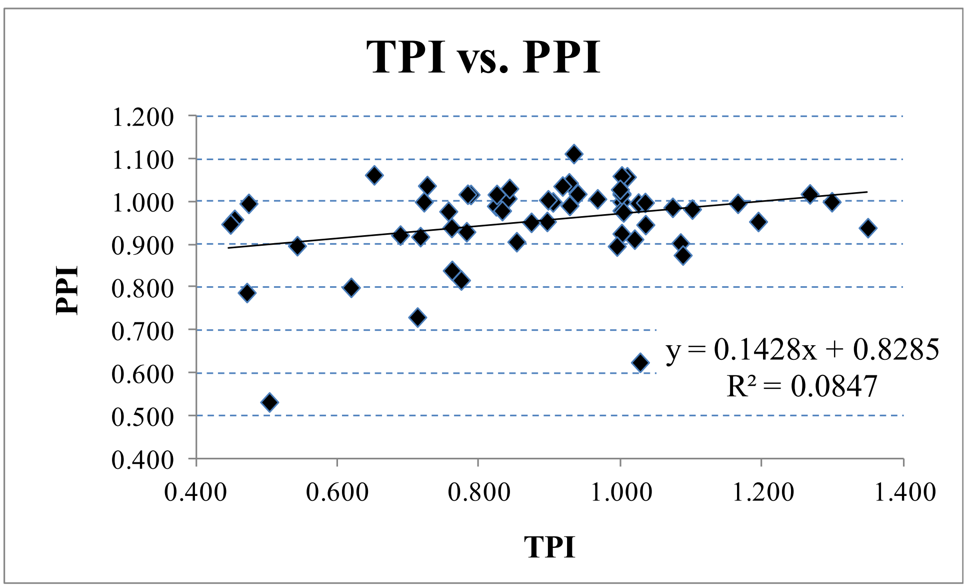


Figure 93 - Scatter plot of TPI vs. PPI

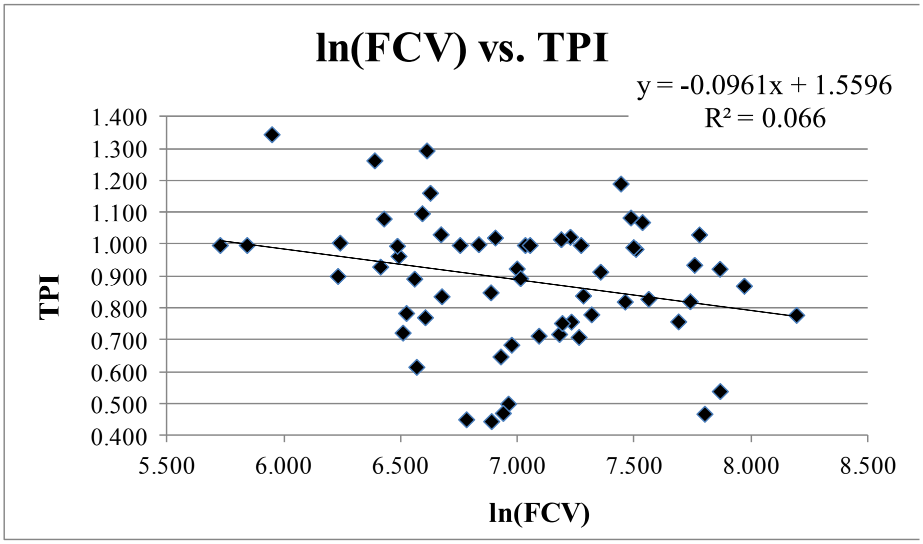


Figure 94 - Scatter plot of natural log of the FCV against the TPI

6.2.2 Categorical Performance and Risks

The analysis described in Chapter 5 included computation of OR and RR values for the various project categories. Table 18 on Page 262 summarizes those values. Among the categories exhibiting the greatest risk of duration escalation includes roads with bridges, urban locations, primary arterials, and dollar value greater than $35 million. Table 60 lists these factors and the OR and RR values for All Projects and Liger projects subset.

Table 60 - List of high-risk categorical factors, All Projects and Liger Projects Subset

Factor	All Projects		Liger Projects	
	OR	RR	OR	RR
Primary Arterial	2.98	1.83	1.86	1.43
Urban Location	2.17	1.79	1.68	1.48
Increase Capacity	1.92	1.53	2.79	1.93
Roads w/Bridges	1.67	1.34	1.71	1.33
>$35 million	6.36	5.12	8.14	6.00

6.2.3 Effect of Constraints and the Associated Risks

The presence of wetlands, streams or waterways, utilities, railroads, and the requirement of phased MOT were identified as having the highest increased risk of all constraints. The full listing of OR and RR values is located in Table 36 on Page 296 of Chapter 5. Table 61 displays the OR, RR, and TPI values associated with the critical constraints for All Projects and Liger Projects subset. The Liger risk values are not considered to be much different from all projects in the final pool. The difference in TPI values between the two subsets is considered more meaningful. For instance, $\Delta_{Li\text{-}All}$ for phased MOT is 0.033. The change represents a decrease in duration escalation of 3% of the OCD.

Table 61 - OR, RR, and TPI values of critical constraints for All Projects and Liger Projects Subset

Constraint	All Projects			Ligers			TPI
	OR	RR	TPI	OR	RR	TPI	$\Delta_{Li\text{-}All}$
Wetlands	1.54	1.32	0.856	1.42	1.24	0.878	0.022
Stream/Waterway	2.44	1.53	0.836	2.85	2.85	0.861	0.025
Phased MOT	2.70	1.59	0.841	2.11	1.41	0.874	0.033
Utilities	4.44	2.12	0.827	6.42	2.44	0.828	0.001
Railroad	3.44	2.81	0.801	3.86	3.00	0.811	0.010

The increased risk associated with exposure to these and other constraints and conditions was clearly demonstrated Chapter 5 as was the complexity associated with each constraint. The complexity MSD associated with the various constraints is shown in Table 57 on Page 345. The largest complexity MSD values associated with constraints are for railroads and physical space constraints. In fact, the presence of railroad within project limits has the largest MSD for complexity. The conclusion is that constraints do impose greater risk of duration escalation, the degree of which is dependent upon the constraint itself combination with other factors. Constraints demonstrate complexity and their comparative risks can be described by OR and RR.

6.2.4 Risks Associated with Exposure to Regulatory Agencies

OR and RR values were computed for projects requiring interaction with three different regulatory groups. These included the FHWA, USACOE, and local state DEP. The greatest risk of duration escalation was attributable to the USACOE, with OR and RR values of 1.66 and 1.31, respectively. Projects with FHWA involvement exhibited less risk of duration escalation than the other two with OR and RR values of 0.65 and 0.91.

6.2.5 Schedule Risks

CPM Scheduling exhibited greater risk potential than LSM scheduling, 2.96 and 1.14 vs. 0.75 and 0.77. Only 5 projects in the final pool used LSM compared to 58 for CPM. LSM may be the preferred methodology for certain types of linear construction. The recommendation is to expand use of LSM on projects for which its application is more appropriate than CPM. However, CPM may be better suited for certain bridge projects and other non-linear work.

6.2.6 Constructability and Pre-construction Value Engineering

An NCHRP study report recommended that owners conduct more effective constructability reviews in order to avoid time growth (Thomas and Ellis, 2001). The HPP Study revealed that constructability studies were conducted on 7 projects in the final pool. The resulting OR and RR values for constructability studies was 0.22 and 0.29

respectively. Results from a Chi-square test run indicate that projects, which employed constructability studies, are significantly different from those that did not. These results provide a compelling argument for great use of constructability studies.

Preconstruction value engineering (VE) studies were also shown to reduce risk of duration escalation, with OR and RR values of 0.81 and 0.83. The recommendation is for owners to engage in constructability studies and preconstruction VE early and often through all design phases. Constructability and VE should be major components of a comprehensive risk management effort that should be applied to most projects through all phases of the delivery process leading to commissioning.

6.2.7 Risks for Projects Utilizing Precasting and Offsite Prefabrication

Projects employing precasting for concrete elements and offsite prefabrication of other components appear to have greater risk of duration escalation than those, which do not. The OR and RR values for projects using precasting was 1.92 and 1.53 and 4.08 and 3.58 for jobs requiring offsite prefabrication. The complexity MSD on projects using offsite prefabrication was 5.143, which is 0.170 greater than the MSD of 4.828. The complexity MSD for projects using precasting was actually 0.431 (4.828 – 4.417) lower than the MSD for all projects. This subject is a good topic for future research, especially since the objectives of these strategies includes saving time and money.

6.2.8 Input Variables

The input variables emanating from upstream processes or concurrent project dynamics have association with time performance. Greater MSD values are associated with better performing projects and lower values are associated with higher risk of duration escalation. While precise association was difficult to prove, there was clear difference between the MSD values of the KPIs for On Time and Late performance. Chapter 5 demonstrated correlations between several variables across the different project sets. The strongest and most frequently occurring correlated pairs include AP/C, SQ/T, SQ/EP, and T/EP. The most frequently occurring variables include trust (T), schedule quality (SQ), and effective planning (EP). The importance of the second and third variables and their two-way interdependence with other factors is well understood and elucidated in the literature well beyond the cited reference (Thomas and Ellis 2001). What is conspicuous by its absence is any discussion on the role that trust contributes to supporting other key input variables. Trust is a by-product of team dynamics and was considered a KPI in this study.

Table 62 - List of Key Performance Indicators with MSD values for All, On Time, Late, Bear and Liger project subsets

	KPI Mean Semantic Response Differentials MSD Values with Sample Standard Deviation s						
Key Performance Indicators	**All**	On Time	Late	Δ_{O-L}	Bears	Ligers	Δ_{L-B}
Addressing Constraints	5.033	5.500	4.833	0.667	4.071	5.326	1.255
	1.426	1.724	1.248		0.829	1.446	
Schedule Quality	4.781	5.409	4.452	0.957	3.867	5.061	1.194
	1.568	0.666	1.797		1.598	1.464	
Trust	4.984	5.364	4.786	0.578	4.133	5.245	1.112
	1.409	1.093	1.523		1.125	1.392	
Effective Planning	4.453	4.591	4.381	0.210	3.933	4.612	0.679
	1.718	1.709	1.738		1.668	1.718	
Accurate, Comprehensive Plans	4.453	4.636	4.357	0.279	4.067	4.571	0.504
	1.272	1.293	1.265		0.961	1.339	
Constructability	4.500	4.864	4.310	0.554	4.000	4.653	0.653
	1.168	0.941	1.239		0.845	1.217	
Intra-Agency Communication	5.000	5.095	4.951	0.144	4.533	5.149	0.616
	1.101	0.995	1.161		0.915	1.122	
Aggregated Means	4.744	5.066	4.581	0.484	4.086	4.945	0.859

Trust demonstrated some level of correlation with every other variable considered within this study. Trust demonstrated strong correlation with schedule quality on 4 of the 5 subsets. Trust also demonstrated strong correlation with effective planning for 3 project sets. Trust was a strong or very strongly correlated variable 10 times, the highest frequency in this study. Trust is a metric of intra-group and inter-group interactions in project management and social sciences. The author believes that it should not only be measured on highway projects, but should in fact be fostered and become part of an organization's culture.

Table 62 is a listing of project inputs with MSD values for All, On Time, Late, Bear and Liger project subsets. Figure 95 is a bar chart plot showing aggregated MSD values for All, On Time, Late, Bear and Liger project subsets

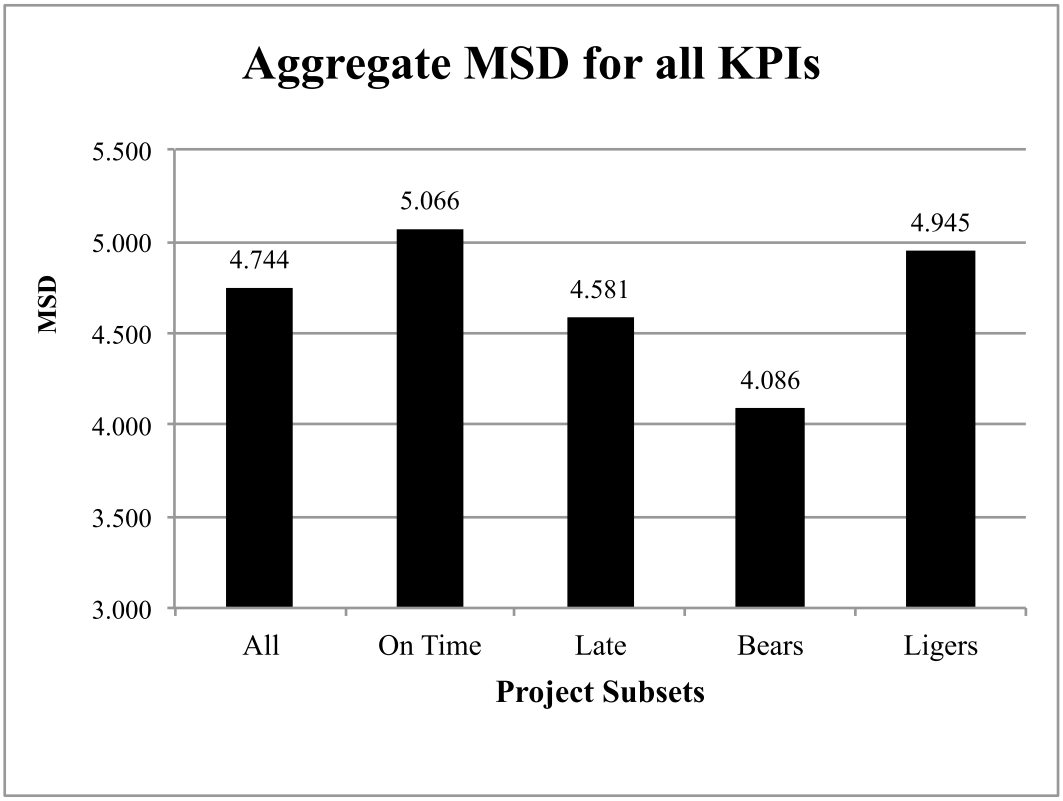


Figure 95 – Bar chart displaying aggregated MSDs for all KPIs

6.2.9 Complexity

Comparative complexity was measured using the semantic differential scale for each project. The MSD of complexity for the entire final pool of projects was 4.824. MSD values were computed for the various project subsets and also for individual factors including categorical groups, practices, and constraints. There were measurable differences in MSD for complexity observed in On Time Projects and Late projects. The study confirmed that complexity is related to other variables and should be viewed as a risk factor in duration escalation. Figure 96 is a scatter plot of complexity against TPI.

Complexity should be considered through all stages of delivery and always reflected within the project risk management framework.

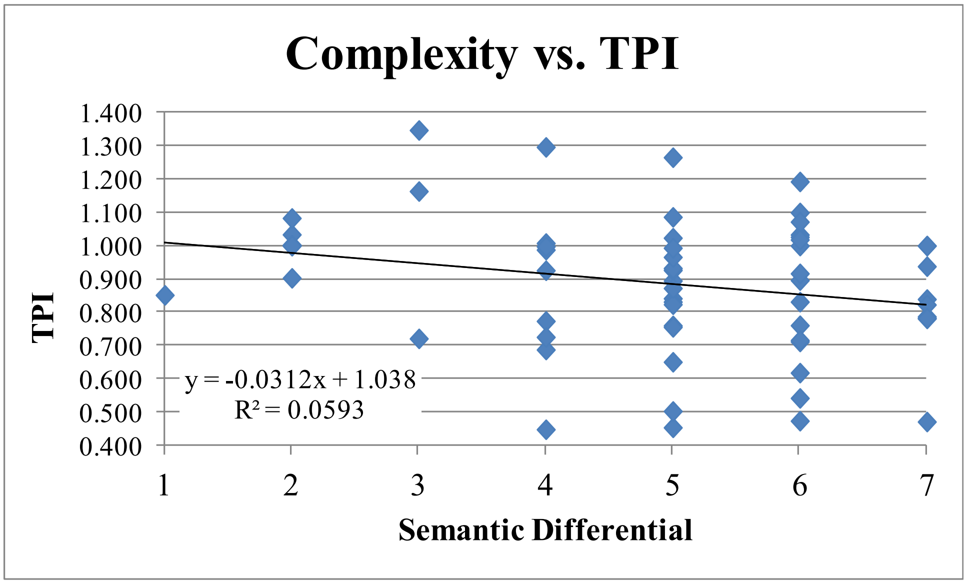


Figure 96 - Scatter plot of complexity against TPI

6.3 Responses to the Proposed Research Questions

The research objectives and expected outcomes were outlined in Section 1.8 of the first chapter. Responses to those questions are embedded in this section. The following questions were posed.

1. *What is the reliability of forecasted project durations?*

Reliability of forecasted project durations was assessed using TPI as the primary metric. As explained in various sections of this thesis, the TPI is an efficiency measurement of time performance that compares final contract duration, FCD, against the original contract duration, OCD. TPI is a measure of magnitude and direction.

The deviation in terms of percentage is computed by subtracting 1 from the reciprocal of the TPI and multiplying the sum by 100, i.e.: $(TPI^{-1}-1)100$. Mean TPI values were computed for various subsets of the project pool, as well as for all projects in the final pool. The mean TPI for all projects the final pool was 0.859, which reflects an average 16.41% escalation above the OCD. Forty (43) or 66.15% of the 65 projects in the final pool were completed beyond the OCD, detected the criteria of TPI<1. This result is believed to be somewhat skewed by the inclusion of the Bear subset of projects. The Liger subset indicates that 30 or 60% of the 50 projects were completed beyond the OCD. The mean TPI for the Liger subset was 0.887, which reflects 12.74% escalation.

2. *How frequently are the original contract durations considered achievable?*

Findings from the HPP Study demonstrated in Section 5.14 of the previous chapter indicate that the original contract durations were achievable and reasonable for 95% of the projects in the final pool and that duration escalation occurred as a result of exposure to risk events that were not effectively mitigated.

3. *What are the causes of duration escalation?*

The top two causes of duration escalation were differing site conditions and owner requested design changes, each representing 19.23% of all causes. Utility conflict was next representing 16.67%, followed by design errors or omissions at 11.54%. Poor contractor performance was cited 8.74%, poor constructability, 5.13% and lack of timely resolution of problems, 3.85%. Many of these are not the sole cause of a projects total escalation, but are at least major contributing factors. There are several other factors impose risk of duration escalation as is demonstrated in Chapter 5.

4. What relationships exist between project variables and time performance?

Input variables that influence time performance fall under the general descriptions of conditions, practices, constraints, and upstream or concurrent processes. Conditions include life cycle, division of work, location, functional class, project purpose, size/range: $ value, project delivery method, designer, and the construction management and inspection services. All of these conditions were assessed for risk and exhibited quantifiable OR and RR values relating to duration escalation. Complexity is a variable of condition. It was quantified in this study using a semantic differential scale. This study demonstrated that as comparative complexity increased, the risk of duration escalation also increased. A negative relationship exists between complexity and time performance.

Practices include techniques or methodologies employed to administer and execute highway construction processes. These include coordination with regulatory agencies, time management methodologies, innovative contracting methods, and expediting strategies. All of these practices were assessed for risk and exhibited quantifiable OR and RR values related to duration escalation.

Constraints in the context of this study refer to anything physical, environmental, or legal in nature that can impede or restrict construction operations. The constraints identified in this study include built environment features such as utilities and railroad. Natural environment elements identified in the study include stream and waterways, wetlands, environmental mitigation, parklands, and fish and wildlife. Any natural or man-made feature can impose physical space limitations. Constraints associated with cultural artifacts include historic landmarks and archeological sites. Contractual or legal constraints include phased MOT, navigation, holidays, union contracts, and noise ordinances. All of these constraints were assessed for risk and exhibited quantifiable OR and RR values related to duration escalation.

Seven input variables measured as KPIs of upstream or concurrent processes were identified in this study. Design outputs included the degree to which constraints were addressed in the contract documents, the accuracy and completeness of the plans, and constructability of the design. Measurement of the contractor's management process included schedule quality and planning effectiveness. Concurrent dynamics include trust and intra-agency communication. All of these variables were measurable as KPI's utilizing a semantic differential scale and all demonstrated a positive relationship with time performance. These variables also demonstrated some level of correlation and exhibit multi-directional relationship.

5. What effect does preconstruction engineering have upon time performance during construction?

Most of the duration escalation due to the causes listed in the response to the third question is directly traceable to the preconstruction engineering phase. Of the occurrences cited to cause time growth, 57.7% were directly attributable to preconstruction engineering. The efficacy of the design process was measured by the three KPIs mentioned in the response to the previous question, namely degree to which constraints were addressed in the contract documents, the accuracy and completeness of the plans, and constructability of the design. The influence of these inputs on construction was measurable against time performance. The MSD of accurate plans for On Time projects was 4.636 and 4.385 for Late projects. The MSD measuring the level of effectiveness in which the plans addressed the constraints was 4.864 for On Time projects and 4.308 for Late projects. The MSD of constructability for On Time projects was 4.864 and 4.308 for Late projects. Furthermore, correlation analysis confirmed a relationship among the design KPIs with the quality of the contractor's schedule and planning effectiveness.

6. *What effect does DOT-contractor interaction have on time performance?*

Trust between the owner and contractor was correlated with all of the other input variables assessed in the study. Trust was measured using a semantic differential scale. Higher MSD values of trust were associated with projects delivered on time. Lower MSD values were found with late performers. The MSD of trust associated with On Time projects was 5.364 and 4.795 for Late projects.

7. *What effect does DOT contract administration have on time performance?*

Lack of timely resolution of problems directly accounted for 3.85% of the causes of duration escalation cited in the study. Intra-agency communication was measured as a KPI of a concurrent dynamic process using a semantic differential scale. Higher MSD values of intra-agency communication found with projects delivered on time. Lower MSD values were found with late performers. The MSD of intra-agency communication associated with On Time projects was 5.095 and 4.895 for Late performers.

This second objective is open-ended and seeks answers to the following questions:

1. *What approaches to management and production from other industries could be successful interventions to address duration escalation on highway projects?*

Project risk management approaches such as those articulated in the *Guide to the Project Management Body of Knowledge or PMBOK® Guide* have application to highway project delivery, beginning with the earliest conceptualization (PMI 2008). Many of the philosophies and management processes collectively known as the Toyota Way have potential application to managing preconstruction and construction phases in highway project delivery. Lean construction concepts continue to emerge and evolve into what appears to be superior to current approaches for delivering constructed facilities. Lean approaches recommended for immediate adoption by state highway agencies include a focus on planning reliability, A3 thinking, and true dedication to continuous improvement in a learning culture.

2. How could or should proposed interventions be implemented?

While sweeping changes and a radical paradigm shift may be warranted, they are seldom successful in positively and continuously transforming an organization. Public highway agencies are bureaucratic in nature and tend to be slow and stodgy. Cultures within these public agencies are very resistant to change. Change must be continuous but slow and implemented incrementally.

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APPENDIX A: PAPER QUESTIONNAIRE

Questionnaire

Highway Project Performance

The United States faces an infrastructure crisis in which deteriorating bridges and highway congestion threaten the economic prosperity and quality of life associated with travel mobility. Transportation professionals are challenged to do more with less in half the time. In response, the Department of Civil, Architectural, and Environmental Engineering at Drexel University is conducting a study to assess current practice and identify strategies to enhance project delivery. This questionnaire is a valuable tool designed to aid in the investigation and understanding of current highway project performance. Your participation in this survey is not only appreciated, but vital to the success of this project. All information is strictly confidential and will be used only for comparative analysis and better understanding of project performance. The final results will be shared with all respondents.

Project Owner: ____________________ Project ID: ____________ (Leave blank)

Project Name: ____________________

Contract No.: ____________________ F.A.P. #: ____________

Location: ____________________ FHWA Full Oversight ☐

Completion Date: ____________________ FHWA Alt. Procedure ☐

Project Manager: ____________________ PM Phone: ____________

Life Cycle Stage	☐ New	☐ restoration/reconstruction/rehab/retrofit		
Division of Work	☐ road work	☐ roads w/bridges	☐ bridge work only	
Location	☐ urban	☐ small urban/suburban	☐ rural	
Functional Class	☐ primary arterial	☐ minor arterial	☐ collector	☐ local road
Project Purpose	☐ increase capacity/improve traffic flow		☐ restoration/maintain function	
	☐ upgrade structural capacity		☐ safety improvement	
Size/range: $ value	☐ 2-4 Million USD	☐ 5-20 Million	☐ 21-35 Million	☐ > 35 Million
Project Delivery	☐ Design-Bid-Build	☐ Design-Build	☐ CM@Risk	☐ PPP
Designer	☐ in-house	☐ consultant	☐ design-builder	☐ contractor alternate

1st Chargeable Day ____________ Contract Completion Date ____________

Orig. contract duration: ________ Calendar Days (CDs) Final construction duration: ________ CDs

Based on the original scope of work **without** considering the effect of weather, was the original contract duration reasonable and achievable? **Yes** ☐ **No** ☐

Time extension granted to the contractor: __________ CDs How many CDs for weather delays? ______

What daily amount was listed for liquidated damages in the contract documents? **$** ____________

Orig. construction cost: ______________ Actual/final construction cost: ______________

The winning bid was how much lower than the 2nd place bid? **$** ______________

Difference in the low bid compared to the Engineer's Estimate **$** ______________

Over ☐ Under ☐

Constraints

☐ Wetlands	☐ Parklands	☐ Archeological	☐ Historic Landmark
☐ Fish/wildlife	☐ Stream/Waterway	☐ Navigation	☐ Winter Shutdown
☐ Phased MOT	☐ Physical Space	☐ Built Env't.	☐ Noise Ordinance
☐ Utilities	☐ Holidays	☐ E. Mitigation	☐ Force Majeure
☐ Railroad	☐ Union Contract	☐ __________	☐ __________

How adequately were the applicable constraints addressed in the contract documents?

Inadequately 1	2	3	4	5	6	**Quite adequately** 7
☐	☐	☐	☐	☐	☐	☐

Coordination with Regulatory Agencies

Federal Highway Administration (FHWA) ☐

U.S. Army Corps of Engineers (USACOE) ☐

State Dept. of Environmental Protection (DEP, DNREC, etc) ☐

Time Management Methodologies/Techniques

CPM Scheduling ☐

Linear Scheduling Method or Line-of-Balance ☐

Last Planner™ ☐

Innovative Contracting Methods or Procedures

Incentive/Disincentive Clause ☐ I/D Daily Amount $ ______________

Best Value Procurement (Adjusted Score Selection, A+B) ☐

Qualifications-based Selection ☐

Lane Rental Method ☐

Value Engineering Study Preconstruction ☐ Contractor VECP ☐

Constructability Study ☐

Formal Pre-construction Risk Assessment ☐

Construction Management and/or Inspection Services

☐ Consultant ☐ Owner ☐ Owner Lead w/Consultant

Post-construction Review

☐ None ☐ Informal ☐ Formal review w/lessons-learned

Contemporary Management Paradigms

☐ IPD ☐ Lean Principles ☐ Six-Sigma ☐ TQM

Expediting Strategies

☐ Precasting ☐ Off-site Prefab ☐ On-site Prefab ☐ Hyper-Build

Which of the following caused the final cost to exceed the original contract amount? Check all that apply.

☐ Design change/plan revision(s)
☐ Adusted final quantities (net increase)
☐ Differing site conditions
☐ Contractor claim or compensable delay
☐ One or more indicated constraints
☐ Other (please explain below)

Which of the following caused the final project duration to exceed the original contract duration or completion date? Check all that apply.

☐ Owner requested design change
☐ Differing or unforeseen site conditions
☐ Design errors or omissions
☐ Poor constructability
☐ Utility conflict
☐ Right-of-Way conflict
☐ Poor contractor performance
☐ Lack of timely resolution of problems
☐ Weather and seasonal impacts
☐ Unrealistic original contract duration
☐ Interference from outside agencies
☐ Lack of commitment
☐ Adusted final quantities
☐ Force Majeure (please explain below)
☐ One or more indicated constraints
☐ Other (please explain below)

Please provide a brief summary of special or extraordinary circumstances which contributed toward post-award cost or time growth

____

____

____

How ambitious was the original construction contract duration? **Not Very** … **Very**

1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

Rank the importance of project outcomes in terms of the triple constraints of cost, quality, and time with 1 being the highest priority and 3 being the lowest: **Cost (budget)** ___ **Quality** ___ **Time (schedule)** ___

Please answer the following question if the final project duration exceeded the original contract duration

If not for the stated occurrences/situations, what is the likelihood that the contractor would have finished the project within the original contract duration? **Not Very** … **Very**

1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

Complexity in highway project construction is a function of: 1) the number and level of physical constraints, i.e.: space, traffic, utilities, wetlands, waterways, railroads, etc.; 2) interdependencies among activities and/or resources; 3) staging (sequence) or phasing of work; 4) contractual and/or other legal constraints; 5) socio-political influence; 6) complexity of details; 7) degree to which work is not linear or repetitive; 8) uncertainty requiring adaptability. Moreover, an increase in the level of complexity requires a corresponding increase in the intensity of management effort to ensure successful project outcomes.

Question							
Given the stated criteria, how complex was this project in comparison to the typical project?	**Not Very**						**Very**
	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Compared to other projects, what was the general quality and effectiveness of the contractor's schedule?	**Poor**						**Excellent**
	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Compared to a typical project, the working relationship and level of trust between the owner and contractor on this contract was:	**Much Worse**						**Much Better**
	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Did the contractor's schedule appear to be produced merely to satisfy a specification requirement or an attempt to provide an effective tool to manage time, resources, and constraints?	**Req't. Satisfaction**						**Effective Tool**
	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐

Were there claims filed by the contractor against the owner? **Yes** ☐ **No** ☐

If so, how many? __________ Were any claims for delay or disruption? **Yes** ☐

Question							
How comprehensive and accurate were the plans and other contract documents compared to the typical project?	**Much Worse**						**Much Better**
	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
How constructable were the plans and details for this contract compared to the typical project?	**Much Worse**						**Much Better**
	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
In general, do you believe that the quality of design plans is increasing or decreasing?	**Decreasing**						**Increasing**
	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Compared to other projects, the level of intra-agency communication within the DOT/SHA on this project was:	**Much Worse**						**Much Better**
	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐

Thank you for taking the time to complete this questionnaire. The collected information shall not be used to criticize or denigrate any project, organization, or individual. Furthermore, reports of the findings shall not reveal performance of specific projects; identify individual contractors, designers, agency employees, etc.; reveal performance of individual agencies to others; single out any one project for any reason - positive or negative. For the sake of objectivity and shielding of participants, the text will not report or categorize the data by state, municipality, or agency but by engineering classifications only. We will be sure to provide you with a report of the findings from this study.

APPENDIX B: SURVEY MONKEY QUESTIONNAIRE

Highway Project Performance

1. HPP Questionnaire

The United States faces an infrastructure crisis in which deteriorating bridges and highway congestion threaten the economic prosperity and quality of life associated with travel mobility. Transportation professionals are challenged to do more with less in half the time. In response, the Department of Civil, Architectural, and Environmental Engineering at Drexel University is conducting a study to assess current practice and identify strategies to enhance project delivery. This questionnaire is a valuable tool designed to aid in the investigation and understanding of current highway project performance. Your participation in this survey is not only appreciated, but vital to the success of this project. All information is strictly confidential and will be used only for comparative analysis and better understanding of project performance. The final results will be shared with all respondents.

1. Project Owner

2. Project Name

3. Contract No:

4. F.A.P. #

5. Location:

6. FHWA Oversight

- ◯ FHWA Full Oversight
- ◯ FHWA Alternate Oversight
- ◯ None

7. Completion Date:

8. Project Manager:

Name

Phone No.

9. Life Cycle Stage

- ◯ New
- ◯ Restoration/reconstruction/rehab/retrofit

Highway Project Performance

10. Division of Work

- ◯ road work
- ◯ roads w/bridges
- ◯ bridge work only

11. Location

- ◯ urban
- ◯ small urban/suburban
- ◯ rural

12. Functional Class

- ◯ primary arterial
- ◯ minor arterial
- ◯ collector
- ◯ local road

13. Project Purpose (primary)

- ◯ increase capacity/improve traffic flow
- ◯ upgrade structural capacity
- ◯ restoration/maintain function
- ◯ safety improvement

14. Size/range: $value (USD)

- ◯ 2-4 Million
- ◯ 5-20 Million
- ◯ 21-35 Million
- ◯ >35 Million

15. Project Delivery Method

- ◯ Design-Bid-Build
- ◯ Design-Build
- ◯ CM@Risk
- ◯ PPP

Highway Project Performance

16. Designer

- ◯ in-house
- ◯ consultant
- ◯ design-builder
- ◯ contractor alternate

17. 1st Chargeable Day

18. Contract Completion Date

19. Orig. contract duration: Calendar Days (CDs)

20. Final construction duration: CDs

2. HPP Questionnaire

1. Based on the original scope of work without considering the effect of weather, was the original contract duration reasonable and achievable?

- ◯ Yes
- ◯ No

2. Time extension granted to the contractor: CDs

3. How many CDs for weather delays?

4. What daily amount was listed for liquidated damages in the contract documents? $

5. Orig. construction cost:$

6. Actual/final construction cost:$

7. The winning bid was how much lower than the 2nd place bid? $

8. Difference in the low bid compared to the Engineer's Estimate: $

9. Was the winning bid over or under the Engineer's Estimate?

- ◯ Over
- ◯ Under

Highway Project Performance

10. What Constraints affected the project? Check all that apply

- [ ] Wetlands
- [ ] Parklands
- [ ] Archaeological
- [ ] Historic Landmark
- [ ] Fish/Wildlife
- [ ] Stream/Waterway
- [ ] Navigation
- [ ] Winter Shutdown
- [ ] Phased MOT
- [ ] Physical Space
- [ ] Built Environment
- [ ] Noise Ordinance
- [ ] Utilities
- [ ] Holidays
- [ ] Environmental Mitigation
- [ ] Force Majeure
- [ ] Railroad
- [ ] Union Contract
- [ ] Other

Other (please specify)

11. How adequately were the applicable constraints addressed in the contract documents?

	1	2	3	4	5	6	7
1=Inadequate 7=Quite adequate	○	○	○	○	○	○	○

12. Coordination with Regulatory Agencies

- [ ] Federal Highway Administration (FHWA)
- [ ] U.S. Army Corps of Engineers (USACOE)
- [ ] State Dept. of Environmental (DEP, DNREC, etc.)

13. Time Management Methodologies/Techniques

- [ ] CPM Scheduling
- [ ] Linear Scheduling Method or Line-of-Balance
- [ ] Last Planner™

Highway Project Performance

14. Innovative Contracting Methods or Procedures

- [ ] Incentive/Disincentive Clause
- [ ] Best Value Procurement (Adjusted Score Selection, A+B)
- [ ] Qualifications-based Selection
- [ ] Lane Rental Method
- [ ] Preconstruction Value Engineering Study
- [ ] Contractor Value Engineering Proposal
- [ ] Constructability Study
- [ ] Formal Preconstruction Risk Assessment

15. If you indicated Incentive/Disincentive Clause, what was the I/D Daily Amount $

3. HPP Questionnaire

1. Construction Management and/or Inspection Services

- ◯ Consultant
- ◯ Owner
- ◯ Owner Lead/COnsultant

2. Post-construction Review

- ◯ None
- ◯ Informal
- ◯ Formal review w/lessons-learned

3. Contemporary Management Paradigms (Check all that apply)

- ☐ IPD
- ☐ Lean Principles
- ☐ Six-Sigma
- ☐ TQM

4. Expediting Strategies (Check all that apply)

- ☐ Precasting
- ☐ Off-site Prefab
- ☐ On-site Prefab
- ☐ Hyper-Build

5. Which of the following caused the final cost to exceed the original contract amount? Check all that apply.

- ☐ Design change/plan revision(s)
- ☐ Adjusted final quantities (net increase)
- ☐ Differing site conditions
- ☐ Contractor claim/compensable delay
- ☐ One or more indicated constraints
- ☐ Other (please specify below)

Other (please specify)

Highway Project Performance

6. Which of the following caused the final project duration to exceed the original contract duration or completion date? Check all that apply.

- ☐ Owner requested design change
- ☐ Differing or unforeseen site conditions
- ☐ Design errors or omissions
- ☐ Poor constructability
- ☐ Utility conflict
- ☐ Right-of-Way conflict
- ☐ Poor contractor performance
- ☐ Lack of timely resolution of problems
- ☐ Weather and seasonal impacts
- ☐ Unrealistic original contract duration
- ☐ Interference from outside agencies
- ☐ Lack of commitment
- ☐ Adjusted final quantities
- ☐ Force Majeure (please explain below
- ☐ One or more indicated constraints
- ☐ Other (please specify below)

Other (please specify)

7. Please provide a brief summary of special or extraordinary circumstances which contributed toward post-award cost or time growth

8. How ambitious was the original construction contract duration?

	1	2	3	4	5	6	7
1=Not Very 7=Very	○	○	○	○	○	○	○

9. Rank the importance of project outcomes in terms of the triple constraints of cost, quality, and time with 1 being the highest priority and 3 being the lowest:

	1	2	3
Cost (budget)	○	○	○
Quality	○	○	○
Time (schedule)	○	○	○

10. Please answer the following question if the final project duration exceeded the original contract duration
If not for the stated occurrences/situations, what is the likelihood that the contractor would have finished the project within the original contract duration?

	1	2	3	4	5	6	7
1=Not Very 7=Very	○	○	○	○	○	○	○

4. HPP Questionnaire

1. Complexity in highway project construction is a function of: 1) the number and level of physical constraints, i.e.: space, traffic, utilities, wetlands, waterways, railroads, etc.; 2) interdependencies among activities and/or resources; 3) staging (sequence) or phasing of work; 4) contractual and/or other legal constraints; 5) socio-political influence; 6) complexity of details; 7) degree to which work is not linear or repetitive; 8) uncertainty requiring adaptability. Moreover, an increase in the level of complexity requires a corresponding increase in the intensity of management effort to ensure successful project outcomes.

Given the stated criteria, how complex was this project in comparison to the typical project?

	1	2	3	4	5	6	7
1=Not Very 7=Very	◯	◯	◯	◯	◯	◯	◯

2. Compared to other projects, what was the general quality and effectiveness of the contractor's schedule?

	1	2	3	4	5	6	7
1=Poor 7=Excellent	◯	◯	◯	◯	◯	◯	◯

3. Compared to a typical project, the working relationship and level of trust between the owner and contractor on this contract was:

	1	2	3	4	5	6	7
1=Much Worse 7=Much Better	◯	◯	◯	◯	◯	◯	◯

4. Did the contractor's schedule appear to be produced merely to satisfy a specification requirement or an attempt to provide an effective tool to manage time, resources, and constraints?

	1	2	3	4	5	6	7
1=Req't Satisfaction 7=Effective Tool	◯	◯	◯	◯	◯	◯	◯

5. Were there claims filed by the contractor against the owner?

◯ Yes

◯ No

If Yes, how many?

Highway Project Performance

6. Were any claims for delay or disruption?

- ◯ Yes
- ◯ No

7. How comprehensive and accurate were the plans and other contract documents compared to the typical project?

	1	2	3	4	5	6	7
1=Much Worse 7=Much Better	◯	◯	◯	◯	◯	◯	◯

8. How constructable were the plans and details for this contract compared to the typical project?

	1	2	3	4	5	6	7
1=Much Worse 7=Much Better	◯	◯	◯	◯	◯	◯	◯

9. In general, do you believe that the quality of design plans is increasing or decreasing?

	1	2	3	4	5	6	7
1=Decreasing 7=Increasing	◯	◯	◯	◯	◯	◯	◯

10. Compared to other projects, the level of intra-agency communication within the DOT/SHA on this project was:

	1	2	3	4	5	6	7
1=Much Worse 7=Much Better	◯	◯	◯	◯	◯	◯	◯

5.

Thank you for taking the time to complete this questionnaire. The collected information shall not be used to criticize or denigrate any project, organization, or individual. Furthermore, reports of the findings shall not reveal performance of specific projects; identify individual contractors, designers, agency employees, etc.; reveal performance of individual agencies to others; single out any one project for any reason - positive or negative. For the sake of objectivity and shielding of participants, the text will not report or categorize the data by state, municipality, or agency but by engineering classifications only. We will be sure to provide you with a report of the findings from this study.

APPENDIX C: HUMAN SUBJECTS RESEARCH TRAINING CERTIFICATE

CERTIFICATE OF COMPLETION

DREXEL UNIVERSITY COLLEGE OF MEDICINE
INSTITUTIONAL REVIEW BOARDS

This is to certify that

Robert W Muir

has successfully completed a training program entitled

HUMAN SUBJECTS RESEARCH

Sreekant Murthy, Ph.D.
Vice Provost for Research Compliance

Certificate Number: 22433
Date Of Certification: 7/2/2009 4:54:00 PM

APPENDIX D: IRB APPROVAL

DREXEL UNIVERSITY COLLEGE OF MEDICINE

Office of Regulatory Research Compliance

APPROVAL NOTICE (EXEMPT)

TO: Robert William Muir , PE, M.S.C.E
Provost / Goodwin College of Prof Studies
Mailstop:

FROM: Sreekant Murthy, Ph.D.

Sreekant Murthy, Ph.D
Vice Provost for Research Compliance
Drexel University College of Medicine
1601 Cherry Street, Suite 10444, 3-Parkway, Philadelphia, Pa 19102
Tel: 215-255-7864 Fax: 215-255-7874

SUBJECT: EXEMPT APPROVAL
TITLE: Application of Lean Theory to Highway Project Delivery Analysis of Highway Project Performance
SPONSOR: Internal
PROJECT No: 1043276, PROTOCOL No: 18451 , ACTION No: 52606 Type: New Period: 1 Seq: 1 , DETAIL No: 257478
CURRENT APPROVAL PERIOD: , EXPIRES:

RE: 08/13/09 - Approved Exempt Category 2. This study will send questionnaires to 7 Department of Transportation agency managers

Date: 8/14/2009

On behalf of the Committee, I am pleased to inform you that the subject protocol has been reviewed and approved as **EXEMPT research** (45 CFR 46, 101(b) (2)) for the period indicated above. We operate under many Government requirements. As a result, this approval is granted with the following understandings:

1. If this is a sponsored project, then the study may not be activated until the Clinical Research Group has received BOTH a fully executed sponsored agreement AND appropriate letter(s) of indemnification by the sponsor. If this is not a sponsored study (designated "internal"), the costs of the project must be identified and a cost center designated. Please call 215-255-7857 if you have any questions regarding these procedures.
2. You must advise the IRB of the activation date. Use the attached form for this purpose.
3. Protected Health Information (PHI) cannot be collected without a Waiver of Authorization per HIPAA regulations.
4. Any change to the protocol must be submitted in writing and approved by the IRB in advance.
5. Any adverse reaction must be reported to the IRB as soon as it occurs.
6. Should the IRB decide to monitor your project directly, please cooperate fully. Failure to do so may

result in withdrawal of this approval and notification to the sponsor and/or Federal agencies. Specific information regarding monitoring appears in the book: "Guidelines for Biomedical and Behavioral Research Involving Human Subjects", obtainable through this office or via the website http://research.drexel.edu.

7. Whether or not this protocol is activated, the IRB will conduct a Continuing Review at least annually. Should you fail to respond to this Federally-required progress report, the project may become ineligible for re-approval and the IRB may choose not to consider other projects for approval.
8. A final progress report must be submitted to the IRB in format similar to that of a periodic report.

The IRB welcomes your research project into the list of approved protocols. Your compliance with the above conditions will help to protect the continuation of all research activity at the University. With your project and others like it, we look forward to additions to knowledge of human health and benefits to science, our patients, and society.

cc: Dept Chair, Tenet, and Drexel

MEMORANDUM
Institutional Review Board (IRB #3)

ACTIVATION NOTICE

TO:	Institutional Review Board (IRB #3) 1601 Cherry Street, Suite 10444, 3-Parkway, Philadelphia, Pa 19102 Tel: 215-255-7864 Fax: 215-255-7874
FROM:	Robert William Muir , PE, M.S.C.E Provost / Goodwin College of Prof Studies
SUBJECT:	ACTIVATION OF HUMAN RESEARCH PROTOCOL ENTITLED: Application of Lean Theory to Highway Project Delivery Analysis of Highway Project Performance PROJECT No: 1043276, PROTOCOL No: 18451, ACTION No: 52606 Type: New Period: 1 Seq: 1 , DETAIL No: 257478 DATE OF APPROVAL: , EXPIRES:
Date:	8/14/2009

This is to inform the IRB that the subject protocol was activated* on __/__/____. I understand that a Periodic Report for Continuing Review or Final Summary is due on or before the above Expiration Date.

[ ] Yes
[ ] No
I have a copy of the University's Human Subjects Guidelines and Federal Wide Assurance (FWA) to the OHRP, as required in 45 CFR Part 46.

NOTE:
The University Guidelines for Biomedical and Behavioral Research for the protection of human subjects have been posted on the Office of Research website.
There are two sets of Guidelines - one each for Medical and Non-Medical Research.
You must have a hard copy and read these Guidelines to make sure that these Guidlines are met.
To download a copy of the University Guidlines, follow the below instructions:

1. Go to http://research.drexel.edu
2. Click "Medical IRB" or "Non-Medical IRB" in Quick Links
3. Under "Go to", click "Medical IRB" or "Non-Medical IRB Guidelines"
4. Please keep a copy of the University Guidelines in your office.

____
(Signed) Muir, Robert William

* "Activated" means that the first new human subject was accrued, or an experimental procedure was performed, or records were reviewed under this protocol on or after the date of last approval: .
Accordingly, this notice must be sent to the IRB ONLY for the FIRST such accrual since that date.

APPENDIX E: HPP STUDY OUTREACH PACKAGE

Highway Project Performance Study

Drexel University
Philadelphia, PA

July 2011

Highway Project Performance Study

Overview

As most transportation professionals are painfully aware, the United States faces an infrastructure crisis in which deteriorating bridges and highway congestion threaten the economic prosperity and quality of life associated with travel mobility. Exacerbating this situation are the funding shortfalls plaguing most highway agencies. Transportation professionals are challenged to do more with less in half the time. In response, the Department of Civil, Architectural, and Environmental Engineering at Drexel University is conducting a study to assess current practice and performance, and identify strategies to enhance project delivery. The first phase includes collection of data related to Highway Project Performance (HPP). The study is conducted from the owner's perspective and includes agencies from the Northeast and Mid-Atlantic regions from New York to North Carolina. The target respondents are professionals working for the participating agencies serving in the capacity of Area Engineer, Project Manager, or Resident Engineer. The requested information includes hard, empirical data mostly related to the project time and cost components. The data collection instrument is a 4-page survey questionnaire available via https://www.surveymonkey.com/s/32ZCHHS. A 4-page paper version of the questionnaire is also available upon request.

The first phase objective is to gain a better understanding of current highway project performance. This includes identifying the input variables of processes, conditions, and constraints under which typical highway projects are delivered. The assessment will attempt to quantify correlations between the explanatory input variables and the dependent outcome variables in order to gain deeper understanding of highway construction project performance, especially in terms of time. The second phase includes identifying potential interventions or countermeasures to address the problems revealed through the first phase of study. This second phase seeks answers to the questions:

1. What approaches to project management and production from other industries could be successful interventions to address duration escalation on highway projects? This includes principles and practices emanating from Lean Project Delivery and other contemporary production and organization management models.
2. How could or should proposed interventions be implemented?

The ultimate product of this work is a set of viable interventions with proposed implementation strategies intended to substantially enhance time performance on highway projects undertaken in the United States. All participants in the study will receive a report of the findings and recommendations. The HPP Study is an unfunded research initiative conducted at no cost to the participating agencies.

Highway Project Performance Study

Instructions for respondents to the Highway Project Performance (HPP) survey

Please use the following link to access the web-based version of the HPP survey questionnaire https://www.surveymonkey.com/s/32ZCHHS.

1.if possible, identify five (5) or more projects completed within the last 5-years for which you have access to the contract records

2. limit selection to original contract values greater than or equal to $2 million

3. exclude paving rehab projects

4. do not select or restrict projects based on whether they were good, poor, or average performers…do not discriminate one way or the other

5. place the name of each project in a hat and draw one project

6. complete the questionnaire for the “drawn” project

7. complete the entire questionnaire

8. be as honest, accurate, and objective as possible

Multiple projects may be submitted and **are in fact appreciated** provided that:

a) one questionnaire is completed per project

b) additional projects are selected randomly

The collected information shall not be used to criticize or denigrate any project, organization, or individual. Furthermore, report of the findings shall not reveal performance of specific projects; identify individual contractors, designers, agency employees, etc.; reveal performance of individual agencies to others; single out any one project for any reason - positive or negative. For the sake of objectivity and shielding of participants, the text will not report or categorize the data by state, municipality, or agency but by engineering classifications only. The Principal Investigator will certainly share the results of the study with all of the respondents. Thank you for your participation!

Highway Project Performance Study

Principal Investigator

Robert Wm. Muir, Jr., PE is the Principal Investigator for the HPP Study. Bob Muir is a licensed Professional Engineer with over 30 years of progressive experience in engineering and construction. He spent 22 of those 30 years engaged in the highway industry. His construction management experience includes representing both the owner and contractor. He has received Awards for Excellence on four bridge and highway projects. He is a member of the Lean Construction Institute, Lean Construction Academic Forum, Construction Management Association of America, and the American Society of Highway Engineers having served as National Director and President of Region 6. In 2002, the First State Section of the American Society of Highway Engineers named him Man of the Year.

After serving as adjunct faculty for some time, Muir followed his passion and entered academia on a full-time basis in 2004. He is currently serving as full-time faculty in the Construction Management Program at Drexel University. He is devoted to the success of our future constructors, increasing the level of professionalism and promoting ethical practice in the construction industry. He is also dedicated to contributing toward the industry's body of knowledge through targeted research initiatives. Currently, Muir is committed to seeking and sharing practical solutions to the many challenges facing the highway industry.

Muir earned a B.S. in Construction Management, Magna cum Laude, from Drexel University and an M.S. in Civil Engineering from Virginia Tech. He is currently pursuing a Ph.D. in Civil Engineering at Drexel University with research intended to identify strategies for enhancing timely delivery of transportation infrastructure. Primary areas of investigation include application of Lean principles and practices, innovative project delivery methods, organizational dynamics, strategic planning, and process and productivity analysis. Bob is also a principal in Construction Analysts, LLC, a private consulting practice specializing in expert analysis and testimony, constructability studies, value engineering, and project risk assessment.

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APPENDIX F: HPP STUDY OUTREACH POSTCARD

Highway Project Performance

Research Questionnaire

We are in the process of collecting data on bridge & highway projects completed within the last 5 years and urgently need your help. You can assist in this important work by completing a questionnaire online at www.surveymonkey.com/s/32ZCHHS. Paper questionnaire forms are also available upon request. Your participation is vital to the success of this effort. Thank you for your support!

For additional information, contact:
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APPENDIX G: HPP STUDY FINAL POOL SPREADSHEET

Internal Ref.	Paper or Web (SM)	Completion Date:	Orig. contract dur (OCD)	Final contract dur. (FCD)	Δt	$\Delta_{TIME}\%$	TPI	Orig. construction value:$	Final construction value:$ (FCV)	$\Delta\$$	$\Delta_{COST}\%$	PPI
3	SM	11/1/06	360	429	-69	-19.2%	0.839	$4,743,840	$4,706,295	$37,545	0.8%	1.008
4	SM	6/29/11	390	458	-68	-17.4%	0.852	$6,917,777	$7,630,998	-$713,221	-10.3%	0.907
5	P	12/4/06	400	582	-182	-45.5%	0.687	$8,636,143	$9,366,822	-$730,679	-8.5%	0.922
6	P	1/5/09	544	580	-36	-6.6%	0.938	$57,926,787	$56,874,807	$1,051,980	1.8%	1.018
7	P	5/29/09	348	389	-41	-11.8%	0.895	$3,430,062	$3,595,690	-$165,627	-4.8%	0.954
8	P	9/3/08	900	1265	-365	-40.6%	0.711	$13,283,117	$18,189,669	-$4,906,553	-36.9%	0.730
9	P	7/13/09	271	598	-327	-120.7%	0.453	$5,752,505	$5,999,495	-$246,990	-4.3%	0.959
10	P	9/27/06	200	447	-247	-123.5%	0.447	$7,280,831	$7,680,729	-$399,898	-5.5%	0.948
11	P	8/26/09	523	506	17	3.3%	1.034	$4,416,079	$4,665,493	-$249,415	-5.6%	0.947
12	P	12/16/08	369	469	-100	-27.1%	0.787	$3,374,004	$3,317,587	$56,418	1.7%	1.017
13	P	1/22/07	257	416	-159	-61.9%	0.618	$2,935,200	$3,670,205	-$735,005	-25.0%	0.800
14	P	6/26/06	416	828	-412	-99.0%	0.502	$4,822,744	$9,071,998	-$4,249,254	-88.1%	0.532
15	P	5/19/09	544	716	-172	-31.6%	0.760	$15,860,387	$16,877,645	-$1,017,258	-6.4%	0.940
16	P	6/10/08	592	639	-47	-7.9%	0.926	$9,791,208	$9,877,255	-$86,047	-0.9%	0.991
17	P	11/21/06	313	289	24	7.7%	1.083	$2,402,599	$2,659,257	-$256,658	-10.7%	0.903
18	P	7/2/08	208	269	-61	-29.3%	0.773	$3,264,699	$3,996,295	-$731,596	-22.4%	0.817
19	SM	2/4/10	730	612	118	16.2%	1.193	$26,241,468	$27,510,151	-$1,268,683	-4.8%	0.954
20	P	10/29/09	265	263	2	0.8%	1.008	$1,825,153	$1,724,425	$100,728	5.5%	1.058
21	P	11/6/08	262	207	55	21.0%	1.266	$2,471,102	$2,426,528	$44,574	1.8%	1.018
22	P	5/17/06	251	278	-27	-10.8%	0.903	$1,687,557	$1,688,189	-$632	0.0%	1.000
24	SM	4/27/09	1,457	1,574	-117	-8.0%	0.926	$76,260,035	$73,028,967	$3,231,068	4.2%	1.044

Internal Ref.	Paper or Web (SM)	Completion Date:	Orig. contract dur (OCD)	Final contract dur. (FCD)	Δt	Δ_{TIME}%	TPI	Orig. construction value:$	Final construction value:$ (FCV)	Δ$	Δ_{COST}%	PPI
25	SM	4/7/11	906	1,257	-351	-38.7%	0.721	$15,000,000	$15,000,000	$0	0.0%	1.000
26	SM	8/15/11	1,128	1,142	-14	-1.2%	0.988	$31,895,000				
27	SM	8/8/11	120	120	0	0.0%	1.000	$528,653	$528,653	$0	0.0%	1.000
28	SM	11/23/10	537	576	-39	-7.3%	0.932	$2,859,728	$2,570,083	$289,644	10.1%	1.113
29	SM	10/15/10	359	359	0	0.0%	1.000	$5,970,114	$5,630,130	$339,984	5.7%	1.060
30	P	12/2/09	832	1536	-704	-84.6%	0.542	$65,678,425	$73,207,285	-$7,528,860	-11.5%	0.897
31	P	9/30/10	1532	1962	-430	-28.1%	0.781	$144,555,441	$155,450,000	-$10,894,559	-7.5%	0.930
32	P	9/4/09	1624	1495	129	7.9%	1.086	$26,562,659	$30,344,864	-$3,782,205	-14.2%	0.875
33	P	5/16/08	881	1872	-991	-112.5%	0.471	$49,547,857	$62,904,873	-$13,357,016	-27.0%	0.788
34	SM	5/31/11	466	617	-151	-32.4%	0.755	$15,089,024	$15,432,632	-$343,608	-2.3%	0.978
35	SM	12/7/09	1046	1022	24	2.3%	1.023	$7,946,789	$7,971,142	-$24,353	-0.3%	0.997
36	SM	10/31/09	786	786	0	0.0%	1.000	$10,923,112	$10,709,399	$213,713	2.0%	1.020
37	SM	6/30/10	832	832	0	0.0%	1.000	$17,186,387	$18,567,088	-$1,380,701	-8.0%	0.926
38	SM	8/31/10	1127	1370	-243	-21.6%	0.823	$28,398,000	$28,672,753	-$274,753	-1.0%	0.990
39	SM	11/11/10	655	731	-76	-11.6%	0.896	$10,267,846	$10,221,300	$46,546	0.5%	1.005
40	SM	8/7/09	536	555	-19	-3.5%	0.966	$3,099,102	$3,078,080	$21,022	0.7%	1.007
41	SM	4/7/11	417	575	-158	-37.9%	0.725	$3,326,263	$3,205,219	$121,044	3.6%	1.038
42	SM	11/9/09	960	960	0	0.0%	1.000	$10,997,700	$11,226,432	-$228,732	-2.1%	0.980
44	SM	3/2/10	537	1,135	-598	-111.4%	0.473	$8,582,669	$8,615,439	-$32,770	-0.4%	0.996
45	SM	5/15/08	558	858	-300	-53.8%	0.650	$8,946,145	$8,416,687	$529,458	5.9%	1.063
46	SM	5/23/10	694	887	-193	-27.8%	0.782	$20,971,655	$20,609,352	$362,304	1.7%	1.018

Internal Ref.	Paper or Web (SM)	Completion Date:	Orig. contract dur (OCD)	Final contract dur. (FCD)	Δt	Δ_{TIME}%	TPI	Orig. construction value:$	Final construction value:$ (FCV)	Δ$	Δ_{COST}%	PPI
47	SM	4/30/07	408	407	1	0.2%	1.002	$6,610,750	$6,772,741	-$161,991	-2.5%	0.976
48	SM	2/24/11	961	1,142	-181	-18.8%	0.842	$19,588,000	$18,996,566	$591,434	3.0%	1.031
49	SM	4/30/10	1,202	1,446	-244	-20.3%	0.831	$35,408,791	$36,156,504	-$747,713	-2.1%	0.979
50	SM	4/30/10	1,202	1,446	-244	-20.3%	0.831					
51	SM	6/1/11	1,104	1,452	-348	-31.5%	0.760	$40,757,489	$48,554,683	-$7,797,193	-19.1%	0.839
52	SM	5/18/11	1,250	1,210	40	3.2%	1.033	$59,561,889	$59,661,298	-$99,409	-0.2%	0.998
53	P	7/20/08	1022	1241	-219	-21.4%	0.824	$55,426,296	$54,492,281	$934,016	1.7%	1.017
54	SM	8/11/11	855	933	-78	-9.1%	0.916	$23,342,657	$22,514,445	$828,212	3.5%	1.037
55	SM	5/4/11	829	808	21	2.5%	1.026	$10,428,909	$16,701,093	-$6,272,184	-60.1%	0.624
56	SM	3/31/09	1257	1441	-184	-14.6%	0.872	$88,382,400	$92,855,163	-$4,472,763	-5.1%	0.952
57	SM	8/19/10	330	330	0	0.0%	1.000	$701,034	$689,122	$11,912	1.7%	1.017
59	P	7/22/08	508	462	46	9.1%	1.100	$3,812,696	$3,879,403	-$66,707	-1.7%	0.983
60	P	7/31/09	687	960	-273	-39.7%	0.716	$11,258,418	$12,258,852	-$1,000,434	-8.9%	0.918
61	SM	7/30/10	646	555	91	14.1%	1.164	$4,184,961	$4,200,498	-$15,537	-0.4%	0.996
62	SM	4/11/11	1478	1488	-10	-0.7%	0.993	$27,940,873	$31,175,031	-$3,234,159	-11.6%	0.896
63	SM	4/7/10	1268	1183	85	6.7%	1.072	$33,563,800	$34,007,935	-$444,135	-1.3%	0.987
64	SM	6/9/11	252	187	65	25.8%	1.348	$827,041	$880,453	-$53,412	-6.5%	0.939
66	SM	8/20/10	393	386	7	1.8%	1.018	$13,935,448	$15,271,428	-$1,335,980	-9.6%	0.913
67	SM	2/18/09	437	337	100	22.9%	1.297	$4,058,000	$4,058,148	-$148	0.0%	1.000
68	SM	12/1/10	435	436	-1	-0.2%	0.998	$3,121,433	$3,033,245	$88,189	2.8%	1.029

APPENDIX H: CATEGORICAL DATA TABLES

Life Cycle Stage - Contingency Table			
Life Cycle Stage	Performance		
	On Time	Late	Total
New	9	17	26
Restoration/Recon/Rehab/Retrofit	13	26	39
Totals	22	43	65

Life Cycle Stage - Table of Row Percentages			
Life Cycle Stage	Performance		
	On Time	Late	Totals
New	34.62%	65.38%	100%
Restoration/Reconstr/Rehab/Retrofit	33.33%	66.67%	100%
Totals	33.85%	66.15%	100%

Life Cycle Stage - Table of Column Percentages			
Life Cycle Stage	Performance		
	On Time	Late	Totals
New	40.91%	39.53%	40.00%
Restoration/Reconstr/Rehab/Retrofit	59.09%	60.47%	60.00%
Totals	100%	100%	100%

Life Cycle Stage - Table of Total Percentages			
Life Cycle Stage	Performance		
	On Time	Late	Totals
New	13.85%	26.15%	40.00%
Restoration/Reconstr/Rehab/Retrofit	20.00%	40.00%	60.00%
Totals	33.85%	66.15%	100%

Life Cycle Stage - Table of Joint Probabilities			
Life Cycle Stage	Performance		
	On Time	Late	Totals
New	0.14	0.26	0.40
Restoration/Reconstr/Rehab/Retrofit	0.20	0.40	0.60
Totals	0.34	0.66	1.00

Division of Work - Contingency Table

Division of Work	Performance		
	On Time	Late	Total
Road Work	6	10	16
Road Work w/Bridges	8	21	29
Bridges Only	8	12	20
Totals	22	43	65

Division of Work - Table of Row Percentages

Division of Work	Performance		
	On Time	Late	Totals
Road Work	37.50%	62.50%	100%
Road Work w/Bridges	27.59%	72.41%	100%
Bridges Only	40.00%	60.00%	100%
Totals	33.85%	66.15%	100%

Division of Work - Table of Column Percentages

Division of Work	Performance		
	On Time	Late	Totals
Road Work	27.27%	23.26%	24.62%
Road Work w/Bridges	36.36%	48.84%	44.62%
Bridges Only	36.36%	27.91%	30.77%
Totals	100%	100%	100%

Division of Work - Table of Total Percentages

Division of Work	Performance		
	On Time	Late	Totals
Road Work	9.23%	15.38%	24.62%
Road Work w/Bridges	12.31%	32.31%	44.62%
Bridges Only	12.31%	18.46%	30.77%
Totals	33.85%	66.15%	100%

Division of Work - Table of Joint Probabilities

Division of Work	Performance		
	On Time	Late	Totals
Road Work	0.09	0.15	0.25
Road Work w/Bridges	0.12	0.32	0.45
Bridges Only	0.12	0.18	0.31
Totals	0.34	0.66	1.00

Location - Contingency Table			
Location	Performance		
	On Time	Late	Total
Urban	4	14	18
Small urban/suburban	10	12	22
Rural	8	17	25
Totals	22	43	65

Location - Table of Row Percentages			
Location	Performance		
	On Time	Late	Totals
Urban	22.22%	77.78%	100%
Small urban/suburban	45.45%	54.55%	100%
Rural	32.00%	68.00%	100%
Totals	33.85%	66.15%	100%

Location - Table of Column Percentages			
Location	Performance		
	On Time	Late	Totals
Urban	18.18%	32.56%	27.69%
Small urban/suburban	45.45%	27.91%	33.85%
Rural	36.36%	39.53%	38.46%
Totals	100%	100%	100%

Location - Table of Total Percentages			
Location	Performance		
	On Time	Late	Totals
Urban	6.15%	21.54%	27.69%
Small urban/suburban	15.38%	18.46%	33.85%
Rural	12.31%	26.15%	38.46%
Totals	33.85%	66.15%	100%

Location - Table of Joint Probabilities			
Location	Performance		
	On Time	Late	Totals
Urban	0.06	0.22	0.28
Small urban/suburban	0.15	0.18	0.34
Rural	0.12	0.26	0.38
Totals	0.34	0.66	1.00

Functional Class - Contingency Table			
Functional Class	Performance		
	On Time	Late	Total
Primary Arterial	7	25	32
Minor Arterial	7	9	16
Collector	3	5	8
Local Road	5	4	9
Totals	22	43	65

Functional Class - Table of Row Percentages			
Functional Class	Performance		
	On Time	Late	Totals
Primary Arterial	21.88%	78.13%	100%
Minor Arterial	43.75%	56.25%	100%
Collector	37.50%	62.50%	100%
Local Road	55.56%	44.44%	100%
Totals	33.85%	66.15%	100%

Functional Class - Table of Column Percentages			
Functional Class	Performance		
	On Time	Late	Totals
Primary Arterial	31.82%	58.14%	49.23%
Minor Arterial	31.82%	20.93%	24.62%
Collector	13.64%	11.63%	12.31%
Local Road	22.73%	9.30%	13.85%
Totals	100%	100%	100%

Functional Class - Table of Total Percentages			
Functional Class	Performance		
	On Time	Late	Totals
Primary Arterial	10.77%	38.46%	49.23%
Minor Arterial	10.77%	13.85%	24.62%
Collector	4.62%	7.69%	12.31%
Local Road	7.69%	6.15%	13.85%
Totals	33.85%	66.15%	100%

Functional Class - Table of Joint Probabilities			
Functional Class	Performance		
	On Time	Late	Totals
Primary Arterial	0.11	0.38	0.49
Minor Arterial	0.11	0.14	0.25
Collector	0.05	0.08	0.12
Local Road	0.08	0.06	0.14
Totals	0.34	0.66	1.00

Project Purpose - Contingency Table			
Project Purpose	Performance		
	On Time	Late	Total
Increase capacity/improve traffic flow	6	18	24
Upgrade structural capacity	6	6	12
Restoration/maintain function	6	15	21
Safety improvement	4	4	8
Totals	22	43	65

Project Purpose - Table of Row Percentages			
Project Purpose	Performance		
	On Time	Late	Totals
Increase capacity/improve traffic flow	25.00%	75.00%	100%
Upgrade structural capacity	50.00%	50.00%	100%
Restoration/maintain function	28.57%	71.43%	100%
Safety improvement	50.00%	50.00%	100%
Totals	33.85%	66.15%	100%

Project Purpose - Table of Column Percentages			
Project Purpose	Performance		
	On Time	Late	Totals
Increase capacity/improve traffic flow	27.27%	41.86%	36.92%
Upgrade structural capacity	27.27%	13.95%	18.46%
Restoration/maintain function	27.27%	34.88%	32.31%
Safety improvement	18.18%	9.30%	12.31%
Totals	100%	100%	100%

Project Purpose - Table of Total Percentages			
Project Purpose	Performance		
	On Time	Late	Totals
Increase capacity/improve traffic flow	9.23%	27.69%	36.92%
Upgrade structural capacity	9.23%	9.23%	18.46%
Restoration/maintain function	9.23%	23.08%	32.31%
Safety improvement	6.15%	6.15%	12.31%
Totals	33.85%	66.15%	100%

Project Purpose - Table of Joint Probabilities			
Project Purpose	Performance		
	On Time	Late	Totals
Increase capacity/improve traffic flow	0.09	0.28	0.37
Upgrade structural capacity	0.09	0.09	0.18
Restoration/maintain function	0.09	0.23	0.32
Safety improvement	0.06	0.06	0.12
Totals	0.34	0.66	1.00

Size/range: $ value - Contingency Table			
Size/range: $ value	Performance		
	On Time	Late	Total
2-4 Million	10	12	22
5-20 Million	8	16	24
21-35 Million	3	5	8
> 35 Million	1	10	11
Totals	22	43	65

Size/range: $ value - Table of Row Percentages			
Size/range: $ value	Performance		
	On Time	Late	Totals
2-4 Million	45.45%	54.55%	100%
5-20 Million	33.33%	66.67%	100%
21-35 Million	37.50%	62.50%	100%
> 35 Million	9.09%	90.91%	100%
Totals	33.85%	66.15%	100%

Size/range: $ value - Table of Column Percentages			
Size/range: $ value	Performance		
	On Time	Late	Totals
2-4 Million	45.45%	27.91%	33.85%
5-20 Million	36.36%	37.21%	36.92%
21-35 Million	13.64%	11.63%	12.31%
> 35 Million	4.55%	23.26%	16.92%
Totals	100%	100%	100%

Size/range: $ value - Table of Total Percentages			
Size/range: $ value	Performance		
	On Time	Late	Totals
2-4 Million	15.38%	18.46%	33.85%
5-20 Million	12.31%	24.62%	36.92%
21-35 Million	4.62%	7.69%	12.31%
> 35 Million	1.54%	15.38%	16.92%
Totals	33.85%	66.15%	100%

Size/range: $ value - Table of Joint Probabilities			
Size/range: $ value	Performance		
	On Time	Late	Totals
2-4 Million	0.15	0.18	0.34
5-20 Million	0.12	0.25	0.37
21-35 Million	0.05	0.08	0.12
> 35 Million	0.02	0.15	0.17
Totals	0.34	0.66	1.00

Construction Management and/or Inspection Services - Contingency Table			
Construction Management and/or Inspection Services	Performance		
	On Time	Late	Total
Consultant	1	9	10
Owner	10	11	21
Owner Lead w/Consultant	11	23	34
Totals	22	43	65

Construction Management and/or Inspection Services - Table of Row Percentages			
Construction Management and/or Inspection Services	Performance		
	On Time	Late	Totals
Consultant	10.00%	90.00%	100%
Owner	47.62%	52.38%	100%
Owner Lead w/Consultant	32.35%	67.65%	100%
Totals	33.85%	66.15%	100%

Construction Management and/or Inspection Services - Table of Column Percentages			
Construction Management and/or Inspection Services	Performance		
	On Time	Late	Totals
Consultant	4.55%	20.93%	15.38%
Owner	45.45%	25.58%	32.31%
Owner Lead w/Consultant	50.00%	53.49%	52.31%
Totals	100%	100%	100%

Construction Management and/or Inspection Services - Table of Total Percentages			
Construction Management and/or Inspection Services	Performance		
	On Time	Late	Totals
Consultant	1.54%	13.85%	15.38%
Owner	15.38%	16.92%	32.31%
Owner Lead w/Consultant	16.92%	35.38%	52.31%
Totals	33.85%	66.15%	100%

Construction Management and/or Inspection Services - Table of Joint Probabilities			
Construction Management and/or Inspection Services	Performance		
	On Time	Late	Totals
Consultant	0.02	0.14	0.15
Owner	0.15	0.17	0.32
Owner Lead w/Consultant	0.17	0.35	0.52
Totals	0.34	0.66	1.00

Project Delivery - Contingency Table			
Project Delivery	Performance		
	On Time	Late	Total
Design-Bid-Build	21	41	62
Design-Build	1	2	3
CM At-Risk	0	0	0
PPP	0	0	0
Totals	22	43	65

Project Delivery - Table of Row Percentages			
Project Delivery	Performance		
	On Time	Late	Totals
Design-Bid-Build	33.87%	66.13%	100%
Design-Build	33.33%	66.67%	100%
CM At-Risk	0.00%	0.00%	0%
PPP	0.00%	0.00%	0%
Totals	33.85%	66.15%	100%

Project Delivery - Table of Column Percentages			
Project Delivery	Performance		
	On Time	Late	Totals
Design-Bid-Build	95.45%	95.35%	95.38%
Design-Build	4.55%	4.65%	4.62%
CM At-Risk	0.00%	0.00%	0.00%
PPP	0.00%	0.00%	0.00%
Totals	100%	100%	100%

Project Delivery - Table of Total Percentages			
Project Delivery	Performance		
	On Time	Late	Totals
Design-Bid-Build	32.31%	63.08%	95.38%
Design-Build	1.54%	3.08%	4.62%
CM At-Risk	0.00%	0.00%	0.00%
PPP	0.00%	0.00%	0.00%
Totals	33.85%	66.15%	100%

Project Delivery - Table of Joint Probabilities			
Project Delivery	Performance		
	On Time	Late	Totals
Design-Bid-Build	0.32	0.63	0.95
Design-Build	0.02	0.03	0.05
CM At-Risk	0.00	0.00	0.00
PPP	0.00	0.00	0.00
Totals	0.34	0.66	1.00

Designer - Contingency Table			
Designer	Performance		
	On Time	Late	Total
In-house	8	9	17
Consultant	13	32	45
Design-builder	1	2	3
Contractor Alternate	0	0	0
Totals	22	43	65

Designer - Table of Row Percentages			
Designer	Performance		
	On Time	Late	Totals
In-house	47.06%	52.94%	100%
Consultant	28.89%	71.11%	100%
Design-builder	0.00%	0.00%	0%
Contractor Alternate	0.00%	0.00%	0%
Totals	33.85%	66.15%	100%

Designer - Table of Column Percentages			
Designer	Performance		
	On Time	Late	Totals
In-house	36.36%	20.93%	26.15%
Consultant	59.09%	74.42%	69.23%
Design-builder	4.55%	4.65%	4.62%
Contractor Alternate	0.00%	0.00%	0.00%
Totals	100%	100%	100%

Designer - Table of Total Percentages			
Designer	Performance		
	On Time	Late	Totals
In-house	12.31%	13.85%	26.15%
Consultant	20.00%	49.23%	69.23%
Design-builder	1.54%	3.08%	4.62%
Contractor Alternate	0.00%	0.00%	0.00%
Totals	33.85%	66.15%	100%

Designer - Table of Joint Probabilities			
Designer	Performance		
	On Time	Late	Totals
In-house	0.12	0.14	0.26
Consultant	0.20	0.49	0.69
Design-builder	0.02	0.03	0.05
Contractor Alternate	0.00	0.00	0.00
Totals	0.34	0.66	1.00

APPENDIX I: CHI SQUARE TEST OUTPUTS

Chi-Square Test of Life Cycle Stage

Observed Frequencies			
	Life Cycle Stage		
Performance	**New**	**Reconstruction**	**Total**
On Time	9	13	22
Late	17	26	43
Total	26	39	65

Expected Frequencies		pbar =	0.3385
	Life Cycle Stage		
Performance	**New**	**Reconstruction**	**Total**
On Time	8.80	13.20	22
Late	17.20	25.80	43
Total	26	39	65

Data		Calculations	
Level of Significance	**0.05**	fo-fe	
Number of Rows	2	0.20	-0.20
Number of Columns	2	-0.20	0.20
Degrees of Freedom	1		
		(fo-fe)^2/fe	
Results		0.00455	0.00303
Critical Value	**3.8415**	0.00233	0.00155
Chi-Square Test Statistic	**0.0115**		
***p*-Value**	**0.9148**		
Do not reject the null hypothesis			

Expected frequency assumption is met.

Chi-Square Test of Division of Work

Observed Frequencies				
	Division of Work			
Performance	**Road Work**	**Road w/Bridges**	**Bridges Only**	**Total**
On Time	6	8	8	22
Late	10	21	12	43
Total	16	29	20	65

Expected Frequencies			pbar =	0.3385
	Division of Work			
Performance	**Road Work**	**Road w/Bridges**	**Bridges Only**	**Total**
On Time	5.42	9.82	6.77	22
Late	10.58	19.18	13.23	43
Total	16	29	20	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	3
Degrees of Freedom	2

Calculations		
fo-fe		
0.58	-1.82	1.23
-0.58	1.82	-1.23
(fo-fe)^2/fe		
0.06311	0.33576	0.22378
0.03229	0.17178	0.11449

Results	
Critical Value	**5.9915**
Chi-Square Test Statistic	**0.9412**
***p*-Value**	**0.6246**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Location

Observed Frequencies				
	Location			
Performance	**Urban**	**Suburban**	**Rural**	**Total**
On Time	4	10	8	22
Late	14	12	17	43
Total	18	22	25	65

Expected Frequencies			pbar =	0.3385
	Location			
Performance	**Urban**	**Suburban**	**Rural**	**Total**
On Time	6.09	7.45	8.46	22
Late	11.91	14.55	16.54	43
Total	18	22	25	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	3
Degrees of Freedom	2

Calculations		
fo-fe		
-2.09	2.55	-0.46
2.09	-2.55	0.46
(fo-fe)^2/fe		
0.71857	0.87591	0.02517
0.36764	0.44814	0.01288

Results	
Critical Value	**5.9915**
Chi-Square Test Statistic	**2.4483**
***p*-Value**	**0.2940**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Functional Class

Observed Frequencies					
	Functional Class				
Performance	**Primary Arterial**	**Minor Arterial**	**Collector**	**Local Road**	**Total**
On Time	7	7	3	5	22
Late	25	9	5	4	43
Total	32	16	8	9	65

Expected Frequencies				pbar =	0.3385
	Functional Class				
Performance	**Primary Arterial**	**Minor Arterial**	**Collector**	**Local Road**	**Total**
On Time	10.83	5.42	2.71	3.05	22
Late	21.17	10.58	5.29	5.95	43
Total	32	16	8	9	65

Data		Calculations			
Level of Significance	**0.05**	fo-fe			
Number of Rows	2	-3.83	1.58	0.29	1.95
Number of Columns	4	3.83	-1.58	-0.29	-1.95
Degrees of Freedom	3				
		(fo-fe)^2/fe			
Results		1.35492	0.46368	0.03156	1.25322
Critical Value	**7.8147**	0.69321	0.23723	0.01614	0.64118
Chi-Square Test Statistic	**4.6912**				
***p*-Value**	**0.1959**				
Do not reject the null hypothesis					

Expected frequency assumption is met.

Chi-Square Test of Project Purpose

Observed Frequencies					
	Project Purpose				
Performance	Increase Capacity	Upgrade Structure	Maintain Function	Safety Improve.	Total
On Time	6	6	6	4	22
Late	18	6	15	4	43
Total	24	12	21	8	65

Expected Frequencies				pbar =	0.3385
	Project Purpose				
Performance	Increase Capacity	Upgrade Structure	Maintain Function	Safety Improve.	Total
On Time	8.12	4.06	7.11	2.71	22
Late	15.88	7.94	13.89	5.29	43
Total	24	12	21	8	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	4
Degrees of Freedom	3

Results	
Critical Value	**7.8147**
Chi-Square Test Statistic	**3.4306**
***p*-Value**	**0.3299**
Do not reject the null hypothesis	

Calculations			
fo-fe			
-2.12	1.94	-1.11	1.29
2.12	-1.94	1.11	-1.29
(fo-fe)^2/fe			
0.55490	0.92517	0.17263	0.61678
0.28390	0.47335	0.08832	0.31556

Expected frequency assumption is met.

Chi-Square Test of Size/range: $ Value

Observed Frequencies					
	Size/range: $ Value				
Performance	**2-4 Million**	**5-20 Million**	**21-35 Million**	**>35 Million**	**Total**
On Time	10	8	3	1	22
Late	12	16	5	10	43
Total	22	24	8	11	65

Expected Frequencies				pbar =	0.3385
	Size/range: $ Value				
Performance	**2-4 Million**	**5-20 Million**	**21-35 Million**	**>35 Million**	**Total**
On Time	7.45	8.12	2.71	3.72	22
Late	14.55	15.88	5.29	7.28	43
Total	22	24	8	11	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	4
Degrees of Freedom	3

Calculations			
fo-fe			
2.55	-0.12	0.29	-2.72
-2.55	0.12	-0.29	2.72
(fo-fe)^2/fe			
0.87591	0.00186	0.03156	1.99167
0.44814	0.00095	0.01614	1.01899

Results	
Critical Value	**7.8147**
Chi-Square Test Statistic	**4.3852**
***p*-Value**	**0.2228**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Construction Management and/or Inspection Services

Observed Frequencies				
	Construction Management and/or Inspection Services			
Performance	**Consultant**	**Owner**	**Owner Lead**	**Total**
On Time	**1**	**10**	**11**	**22**
Late	**9**	**11**	**23**	**43**
Total	**10**	**21**	**34**	**65**

Expected Frequencies			pbar =	0.3385
	Construction Management and/or Inspection Services			
Performance	Consultant	Owner	Owner Lead	Total
On Time	3.38	7.11	11.51	22
Late	6.62	13.89	22.49	43
Total	10	21	34	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	3
Degrees of Freedom	2

Calculations		
fo-fe		
-2.38	2.89	-0.51
2.38	-2.89	0.51
(fo-fe)^2/fe		
1.68007	1.17696	0.02240
0.85957	0.60216	0.01146

Results	
Critical Value	**5.9915**
Chi-Square Test Statistic	**4.3526**
***p*-Value**	**0.1135**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Project Delivery

Observed Frequencies			
	Project Delivery		
Performance	**DBB**	**DB**	**Total**
On Time	**21**	**1**	**22**
Late	**41**	**2**	**43**
Total	**62**	**3**	**65**

Expected Frequencies			0.3385
	Project Delivery		
Performance	DBB	DB	Total
On Time	20.98	1.02	22
Late	41.02	1.98	43
Total	62	3	65

Data		**Calculations**	
Level of Significance	**0.05**	fo-fe	
Number of Rows	2	0.02	-0.02
Number of Columns	3	-0.02	0.02
Degrees of Freedom	2		
		(fo-fe)^2/fe	
Results		0.00001	0.00023
Critical Value	**5.9915**	0.00001	0.00012
Chi-Square Test Statistic	**0.0004**		
***p*-Value**	**0.9998**		
Do not reject the null hypothesis			

Expected frequency assumption is met.

Chi-Square Test of Designer

Observed Frequencies				
	Designer			
Performance	**In-house**	**Consultant**	**Design-Builder**	**Total**
On Time	**8**	**13**	**1**	**22**
Late	**9**	**32**	**2**	**43**
Total	**17**	**45**	**3**	**65**

Expected Frequencies			pbar =	0.3385
	Designer			
Performance	In-house	Consultant	Design-Builder	Total
On Time	5.75	15.23	1.02	22
Late	11.25	29.77	1.98	43
Total	17	45	3	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	3
Degrees of Freedom	2

Results	
Critical Value	**5.9915**
Chi-Square Test Statistic	**1.8197**
***p*-Value**	**0.4026**
Do not reject the null hypothesis	

Calculations		
fo-fe		
2.25	-2.23	-0.02
-2.25	2.23	0.02
(fo-fe)^2/fe		
0.87684	0.32673	0.00023
0.44862	0.16716	0.00012

Expected frequency assumption is met.

Chi-Square Test of Wetlands

Observed Frequencies			
	Wetlands		
Performance	Present	Not Present	Total
Late	18	25	43
On Time	7	15	22
Total	25	40	65

Expected Frequencies		pbar =	0.6615
	Wetlands		
Performance	Present	Not Present	Total
Late	16.54	26.46	43
On Time	8.46	13.54	22
Total	25	40	65

Data		Calculations	
Level of Significance	**0.05**	fo-fe	
Number of Rows	2	1.46	-1.46
Number of Columns	2	-1.46	1.46
Degrees of Freedom	1		
		(fo-fe)^2/fe	
Results		0.12916	0.08072
Critical Value	**3.8415**	0.25245	0.15778
Chi-Square Test Statistic	**0.6201**		
***p*-Value**	**0.4310**		
Do not reject the null hypothesis			

Expected frequency assumption is met.

Chi-Square Test of Parklands

Observed Frequencies			
	Parklands		
Performance	**Present**	**Not Present**	**Total**
Late	2	41	43
On Time	1	21	22
Total	3	62	65

Expected Frequencies		pbar =	0.6615
	Parklands		
Performance	**Present**	**Not Present**	**Total**
Late	1.98	41.02	43
On Time	1.02	20.98	22
Total	3	62	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**0.0004**
***p*-Value**	**0.9847**
Do not reject the null hypothesis	

Calculations	
fo-fe	
0.02	-0.02
-0.02	0.02
(fo-fe)^2/fe	
0.00012	0.00001
0.00023	0.00001

Expected frequency assumption is met.

Chi-Square Test of Archaeological

Observed Frequencies			
	Archaeological		
Performance	**Present**	**Not Present**	**Total**
Late	2	41	43
On Time	3	19	22
Total	5	60	65

Expected Frequencies		pbar =	0.6615
	Archaeological		
Performance	**Present**	**Not Present**	**Total**
Late	3.31	39.69	43
On Time	1.69	20.31	22
Total	5	60	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Calculations	
fo-fe	
-1.31	1.31
1.31	-1.31
(fo-fe)^2/fe	
0.51699	0.04308
1.01049	0.08421

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**1.6548**
***p*-Value**	**0.1983**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Historic Landmark

Observed Frequencies			
	Historic Landmark		
Performance	Present	Not Present	Total
Late	6	37	43
On Time	3	19	22
Total	9	56	65

Expected Frequencies		pbar =	0.6615
	Historic Landmark		
Performance	Present	Not Present	Total
Late	5.95	37.05	43
On Time	3.05	18.95	22
Total	9	56	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Calculations	
fo-fe	
0.05	-0.05
-0.05	0.05
(fo-fe)^2/fe	
0.00036	0.00006
0.00070	0.00011

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**0.0012**
***p*-Value**	**0.9721**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Fish/Wildlife

Observed Frequencies			
	Fish/Wildlife		
Performance	**Present**	**Not Present**	**Total**
Late	9	34	43
On Time	6	16	22
Total	15	50	65

Expected Frequencies		pbar =	0.6615
	Fish/Wildlife		
Performance	**Present**	**Not Present**	**Total**
Late	9.92	33.08	43
On Time	5.08	16.92	22
Total	15	50	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Calculations	
fo-fe	
-0.92	0.92
0.92	-0.92
(fo-fe)^2/fe	
0.08587	0.02576
0.16783	0.05035

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**0.3298**
***p*-Value**	**0.5658**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Stream/Waterway

Observed Frequencies			
	Stream/Waterway		
Performance	**Present**	**Not Present**	**Total**
Late	27	16	43
On Time	9	13	22
Total	36	29	65

Expected Frequencies		pbar =	0.6615
	Stream/Waterway		
Performance	**Present**	**Not Present**	**Total**
Late	23.82	19.18	43
On Time	12.18	9.82	22
Total	36	29	65

Data		Calculations	
Level of Significance	**0.05**	fo-fe	
Number of Rows	2	3.18	-3.18
Number of Columns	2	-3.18	3.18
Degrees of Freedom	1		
		(fo-fe)^2/fe	
Results		0.42585	0.52864
Critical Value	**3.8415**	0.83234	1.03325
Chi-Square Test Statistic	**2.8201**		
***p*-Value**	**0.0931**		
Do not reject the null hypothesis			

Expected frequency assumption is met.

Chi-Square Test of Navigation

Observed Frequencies			
	Navigation		
Performance	Present	Not Present	Total
Late	5	38	43
On Time	4	18	22
Total	9	56	65

Expected Frequencies		pbar =	0.6615
	Navigation		
Performance	Present	Not Present	Total
Late	5.95	37.05	43
On Time	3.05	18.95	22
Total	9	56	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Calculations	
fo-fe	
-0.95	0.95
0.95	-0.95
(fo-fe)^2/fe	
0.15281	0.02456
0.29868	0.04800

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**0.5241**
***p*-Value**	**0.4691**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Winter Shutdown

Observed Frequencies			
	Winter Shutdown		
Performance	**Present**	**Not Present**	**Total**
Late	17	26	43
On Time	6	16	22
Total	23	42	65

Expected Frequencies		pbar =	0.6615
	Winter Shutdown		
Performance	**Present**	**Not Present**	**Total**
Late	15.22	27.78	43
On Time	7.78	14.22	22
Total	23	42	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Calculations	
fo-fe	
1.78	-1.78
-1.78	1.78
(fo-fe)^2/fe	
0.20932	0.11463
0.40912	0.22404

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**0.9571**
***p*-Value**	**0.3279**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Phased MOT

Observed Frequencies			
	Phased MOT		
Performance	**Present**	**Not Present**	**Total**
Late	28	15	43
On Time	9	13	22
Total	37	28	65

Expected Frequencies		pbar =	0.6615
	Phased MOT		
Performance	**Present**	**Not Present**	**Total**
Late	24.48	18.52	43
On Time	12.52	9.48	22
Total	37	28	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Calculations	
fo-fe	
3.52	-3.52
-3.52	3.52
(fo-fe)^2/fe	
0.50709	0.67009
0.99114	1.30972

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**3.4780**
***p*-Value**	**0.0622**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Physical Space

Observed Frequencies			
	Physical Space		
Performance	**Present**	**Not Present**	**Total**
Late	17	26	43
On Time	8	14	22
Total	25	40	65

Expected Frequencies		pbar =	0.6615
	Physical Space		
Performance	**Present**	**Not Present**	**Total**
Late	16.54	26.46	43
On Time	8.46	13.54	22
Total	25	40	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**0.0618**
***p*-Value**	**0.8036**
Do not reject the null hypothesis	

Calculations	
fo-fe	
0.46	-0.46
-0.46	0.46
(fo-fe)^2/fe	
0.01288	0.00805
0.02517	0.01573

Expected frequency assumption is met.

Chi-Square Test of Built Environment

Observed Frequencies			
	Built Environment		
Performance	**Present**	**Not Present**	**Total**
Late	2	41	43
On Time	1	21	22
Total	3	62	65

Expected Frequencies		pbar =	0.6615
	Built Environment		
Performance	**Present**	**Not Present**	**Total**
Late	1.98	41.02	43
On Time	1.02	20.98	22
Total	3	62	65

Data		Calculations	
Level of Significance	**0.05**	fo-fe	
Number of Rows	2	0.02	-0.02
Number of Columns	2	-0.02	0.02
Degrees of Freedom	1		
		(fo-fe)^2/fe	
Results		0.00012	0.00001
Critical Value	**3.8415**	0.00023	0.00001
Chi-Square Test Statistic	**0.0004**		
***p*-Value**	**0.9847**		
Do not reject the null hypothesis			

Expected frequency assumption is met.

Chi-Square Test of Noise Ordinance

Observed Frequencies			
	Noise Ordinance		
Performance	**Present**	**Not Present**	**Total**
Late	3	40	43
On Time	1	21	22
Total	4	61	65

Expected Frequencies		pbar =	0.6615
	Noise Ordinance		
Performance	**Present**	**Not Present**	**Total**
Late	2.65	40.35	43
On Time	1.35	20.65	22
Total	4	61	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**0.1490**
***p*-Value**	**0.6995**
Do not reject the null hypothesis	

Calculations	
fo-fe	
0.35	-0.35
-0.35	0.35
(fo-fe)^2/fe	
0.04732	0.00310
0.09248	0.00606

Expected frequency assumption is met.

Chi-Square Test of Utilities

Observed Frequencies			
	Utilities		
Performance	**Present**	**Not Present**	**Total**
Late	29	14	43
On Time	7	15	22
Total	36	29	65

Expected Frequencies		pbar =	0.6615
	Utilities		
Performance	**Present**	**Not Present**	**Total**
Late	23.82	19.18	43
On Time	12.18	9.82	22
Total	36	29	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**7.4745**
***p*-Value**	**0.0063**
Reject the null hypothesis	

Calculations	
fo-fe	
5.18	-5.18
-5.18	5.18
(fo-fe)^2/fe	
1.12869	1.40114
2.20608	2.73858

Expected frequency assumption is met.

Chi-Square Test of Holidays

Observed Frequencies			
	Holidays		
Performance	**Present**	**Not Present**	**Total**
Late	11	32	43
On Time	4	18	22
Total	15	50	65

Expected Frequencies		pbar =	0.6615
	Holidays		
Performance	**Present**	**Not Present**	**Total**
Late	9.92	33.08	43
On Time	5.08	16.92	22
Total	15	50	65

Data	
Level of Significance	**0.05**
Number of Rows	2
Number of Columns	2
Degrees of Freedom	1

Calculations	
fo-fe	
1.08	-1.08
-1.08	1.08
(fo-fe)^2/fe	
0.11688	0.03506
0.22844	0.06853

Results	
Critical Value	**3.8415**
Chi-Square Test Statistic	**0.4489**
***p*-Value**	**0.5029**
Do not reject the null hypothesis	

Expected frequency assumption is met.

Chi-Square Test of Environmental Mitigation

Observed Frequencies			
	Environmental Mitigation		
Performance	**Present**	**Not Present**	**Total**
Late	10	33	43
On Time	5	17	22
Total	15	50	65

Expected Frequencies		pbar =	0.6615
	Environmental Mitigation		
Performance	**Present**	**Not Present**	**Total**
Late	9.92	33.08	43
On Time	5.08	16.92	22
Total	15	50	65

Data		Calculations	
Level of Significance	**0.05**	fo-fe	
Number of Rows	2	0.08	-0.08
Number of Columns	2	-0.08	0.08
Degrees of Freedom	1		
		(fo-fe)^2/fe	
Results		0.00060	0.00018
Critical Value	**3.8415**	0.00117	0.00035
Chi-Square Test Statistic	**0.0023**		
***p*-Value**	**0.9618**		
Do not reject the null hypothesis			

Expected frequency assumption is met.

Chi-Square Test of Railroad

Observed Frequencies			
	Railroad		
Performance	**Present**	**Not Present**	**Total**
Late	11	32	43
On Time	2	20	22
Total	13	52	65

Expected Frequencies		pbar =	0.6615
	Railroad		
Performance	**Present**	**Not Present**	**Total**
Late	8.60	34.40	43
On Time	4.40	17.60	22
Total	13	52	65

Data		**Calculations**	
Level of Significance	**0.05**	fo-fe	
Number of Rows	2	2.40	-2.40
Number of Columns	2	-2.40	2.40
Degrees of Freedom	1		
		(fo-fe)^2/fe	
Results		0.66977	0.16744
Critical Value	**3.8415**	1.30909	0.32727
Chi-Square Test Statistic	**2.4736**		
***p*-Value**	**0.1158**		
Do not reject the null hypothesis			

Expected frequency assumption is met.

Chi-Square Test of Union Contract

Observed Frequencies			
	Union Contract		
Performance	Present	Not Present	Total
Late	3	40	43
On Time	0	22	22
Total	3	62	65

Expected Frequencies		pbar =	0.6615
	Union Contract		
Performance	Present	Not Present	Total
Late	1.98	41.02	43
On Time	1.02	20.98	22
Total	3	62	65

Data		Calculations	
Level of Significance	**0.05**	fo-fe	
Number of Rows	2	1.02	-1.02
Number of Columns	2	-1.02	1.02
Degrees of Freedom	1		
		(fo-fe)^2/fe	
Results		0.51950	0.02514
Critical Value	**3.8415**	1.01538	0.04913
Chi-Square Test Statistic	**1.6092**		
***p*-Value**	**0.2046**		
Do not reject the null hypothesis			

Expected frequency assumption is met.

APPENDIX J: LIQUIDATED DAMAGES DATA ANALYSIS

Liquidated Damages Data Analysis					
Internal Ref. #	LD (Daily $)	LD as % of OCV	TPI_{LD}	$TPI_{LD - TPI62}$	LD Strength Factor
4	1,130	0.02%	0.852	-0.033	-0.491
6	8,610	0.00%	0.938	0.053	0.000
7	1,010	0.01%	0.895	0.010	1.516
8	3,320	0.03%	0.711	-0.173	-0.170
9	1,250	0.02%	0.453	-0.432	-0.058
10	1,990	0.02%	0.447	-0.437	-0.050
15	2,990	0.03%	0.760	-0.125	-0.219
16	950	0.00%	0.926	0.042	0.000
17	845	0.00%	1.083	0.198	0.000
18	1,010	0.00%	0.773	-0.112	0.000
19	2,000	0.00%	1.193	0.308	0.000
20	630	0.02%	1.008	0.123	0.154
21	920	0.01%	1.266	0.381	0.025
22	785	0.04%	0.903	0.018	1.945
24	5,000	0.03%	0.926	0.041	0.757
25	2,000	0.01%	0.721	-0.164	-0.046
26	2,800	0.03%	0.988	0.103	0.335
27	400	0.04%	1.000	0.115	0.323
28	800	0.05%	0.932	0.047	0.979
29	1,000	0.01%	1.000	0.115	0.057
30	10,400	0.01%	0.542	-0.343	-0.039
31	4,400	0.01%	0.781	-0.104	-0.084
32	7,400	0.08%	1.086	0.201	0.376
34	4,000	0.03%	0.755	-0.130	-0.216
35	2,500	0.02%	1.023	0.139	0.121
36	4,000	0.02%	1.000	0.115	0.137
37	4,000	0.00%	1.000	0.115	0.026
38	7,000	0.03%	0.823	-0.062	-0.448
40	1,100	0.03%	0.966	0.081	0.327
41	1,645	0.03%	0.725	-0.160	-0.197

Liquidated Damages Impact Assessment and Summary					
Internal Ref. #	LD (Daily $)	LD as % of OCV	TPI_{LD}	$TPI_{LD - TPI62}$	LD Strength Factor
42	1,200	0.04%	1.000	0.115	0.318
44	2,200	0.02%	0.473	-0.412	-0.057
45	4,500	0.02%	0.650	-0.234	-0.105
47	1,975	0.01%	1.002	0.118	0.124
48	1,975	0.04%	0.842	-0.043	-0.820
49	1,975	0.05%	0.831	-0.054	-0.924
51	1,975	0.01%	0.760	-0.124	-0.088
52	9,000	0.03%	1.033	0.148	0.173
53	50,000	0.05%	0.824	-0.061	-0.821
54	4,430	0.00%	0.916	0.032	0.000
55	4,420	0.03%	1.026	0.141	0.212
56	2,600	0.01%	0.872	-0.012	-0.808
57	700	0.01%	1.000	0.115	0.048
60	2,500	0.00%	0.716	-0.169	-0.029
61	1,350	0.02%	1.164	0.279	0.054
62	3,100	0.09%	0.993	0.108	0.832
63	3,600	0.02%	1.072	0.187	0.101
64	600	0.04%	1.348	0.463	0.092
66	3,230	0.00%	1.018	0.133	0.022
67	1,390	0.10%	1.297	0.412	0.242
68	1,390	0.09%	0.998	0.113	0.813

APPENDIX K: ANALYSIS OF THE EFFECT OF BID GAP

Analysis of the Effect of Bid Gap						
Internal Ref. #	Bid Gap $	Bid Gap %	Δ 2nd pl. vs. FCV $	Δ FCV vs. 2nd place bid as % of FCV	TPI	PPI
3	937,283	19.76%	974,828	20.71%	0.839	1.008
4	238,029	3.44%	-475,192	-6.23%	0.852	0.907
5	558,095	6.46%	-172,584	-1.84%	0.687	0.922
6	5,588,962	9.65%	6,640,942	11.68%	0.938	1.018
7	21,057	0.61%	-144,570	-4.02%	0.895	0.954
8	522,686	3.93%	-4,383,866	-24.10%	0.711	0.730
9	509,835	8.86%	262,845	4.38%	0.453	0.959
10	8,133	0.11%	-391,765	-5.10%	0.447	0.948
11	335,829	7.60%	86,414	1.85%	1.034	0.947
13	137,616	4.69%	-597,389	0.00%	0.618	0.800
15	396,708	2.50%	-620,550	-16.28%	0.760	0.940
16	1,769,009	18.07%	1,682,962	-46.84%	0.926	0.991
17	292,892	12.19%	36,234	-3.68%	1.083	0.903
18	62,169	1.90%	-669,427	17.04%	0.773	0.817
19	80,843	0.31%	-1,187,841	1.36%	1.193	0.954
20	41,134	2.25%	141,862	-16.75%	1.008	1.058
21	154,899	6.27%	199,472	-4.32%	1.266	1.018
22	35,864	2.13%	35,232	8.23%	0.903	1.000
24	481,200	0.63%	3,712,268	8.22%	0.926	1.044
25	200,000	1.33%	200,000	2.09%	0.721	1.000
28	652,493	22.82%	942,137	1.33%	0.932	1.113
29	454,302	7.61%	794,286	14.11%	1.000	1.060
30	8,758,018	13.33%	1,229,158	1.68%	0.542	0.897
31	17,000,000	11.76%	6,105,441	36.66%	0.781	0.930
32	609,487	2.29%	-3,172,718	14.11%	1.086	0.875
33	2,034,143	4.11%	-11,322,873	1.68%	0.471	0.788
34	698,701	4.63%	355,093	3.93%	0.755	0.978
35	920,772	11.59%	896,419	-10.46%	1.023	0.997
36	410,054	3.75%	623,767	-18.00%	1.000	1.020
37	1,324,813	7.71%	-55,888	2.30%	1.000	0.926

Analysis of the Effect of Bid Gap						
Internal Ref. #	Bid Gap $	Bid Gap %	Δ 2nd pl. vs. FCV $	Δ FCV vs. 2nd place bid as % of FCV	TPI	PPI
38	2,408,422	8.48%	2,133,670	11.25%	0.823	0.990
39	231,891	2.26%	278,437	5.82%	0.896	1.005
40	598,502	19.31%	619,524	-0.30%	0.966	1.007
41	240,963	7.24%	362,007	7.44%	0.725	1.038
42	89,482	0.81%	-139,250	2.72%	1.000	0.980
44	397,000	4.63%	364,230	20.13%	0.473	0.996
45	331,000	3.70%	860,458	11.29%	0.650	1.063
47	567,750	8.59%	405,759	-1.24%	1.002	0.976
48	897,875	4.58%	1,489,309	4.23%	0.842	1.031
51	3,831,082	9.40%	-3,966,111	10.22%	0.760	0.839
52	1,020,000	1.71%	920,591	0.00%	1.033	0.998
53	3,187,342	5.75%	4,121,357	5.99%	0.824	1.017
54	95,000	0.41%	923,212	7.84%	0.916	1.037
55	729,091	6.99%	-5,543,093	-33.19%	1.026	0.624
56	3,595,163	4.07%	-877,600	-0.95%	0.872	0.952
57	11,722	1.67%	23,634	-8.17%	1.000	1.017
59	975,717	25.59%	909,011	1.54%	1.100	0.983
60	714,739	6.35%	-285,695	7.56%	0.716	0.918
62	1,750,475	6.26%	-1,483,683	4.10%	0.993	0.896
64	15,128	1.83%	-38,285	-33.19%	1.348	0.939
66	338,552	2.43%	-997,428	-0.95%	1.018	0.913
67	9,680	0.24%	9,532	3.43%	1.297	1.000
68	255,792	8.19%	343,981	23.43%	0.998	1.029

VITA

Robert William Muir, Jr.

Education

- Drexel University, Bachelor of Science, Construction Management
- Virginia Polytechnic Institute and State University, Master of Science in Civil Engineering, Construction Engineering and Management

Professional Registrations

- Licensed Professional Engineer, State of Delaware, 9654

Professional Experience

- Drexel University, September 2005 – Present (August 2010)
  Philadelphia, PA
  - Assistant Clinical Professor developing and teaching construction management courses
  - Executive Director of the Drexel Construction Management Advisory Council
- University of Delaware, September 1999 – May 2009
  Newark, DE
  - Part-time faculty teaching construction and project management courses in the Department of Civil and Environmental Engineering
- Virginia Polytechnic Institute and State University, September 2004 – May 2005
  Blacksburg, VA
  - Graduate Research Assistant investigating training and development in construction, innovative project delivery, and IT in construction
- Greggo & Ferrara, Inc., July 1997 – August 2004
  New Castle, DE
  - Senior Project Manager in charge of various bridge and highway projects in Delaware
- Pavlo Engineering Co., et al, September 1983 – June 1997
  New York, NY • Bridgeport, NJ • Chester, PA • Wilmington, DE
  - Resident Engineer representing the owner on several bridge and highway bridges in Delaware
  - Conducted engineering and control surveys in New Jersey, New York, Massachusetts, Pennsylvania, and West Virginia
  - Condition inspection of bridges in Connecticut, New Jersey, New York, and West Virginia
  - Management and staff development for regional offices in Pennsylvania, New Jersey, and Delaware
- Phoenix Steel Corporation, August 1978 – September 1983
  Claymont, DE • Phoenixville, PA
  - Field/Project Engineer assigned to $55 million capital improvement program.
- Ludwig Honold Mfg. Co., June 1974 – March 1977
  Folcroft, PA • Edgemoor, DE
  - Draftsman preparing detail, assembly, and erection drawings for fabricated structural and mechanical components

Honors and Awards

- American Society of Highway Engineers (ASHE) First State Section Man of the Year, 2002
- DelDOT 2003 Outstanding Bridge Project – I-95 over Brandywine River, Construction Management
- 2001 Construction Excellence Award, State of Delaware and Delaware Contractors Association, Churchmans Rd - SR 7 Interchange
- DelDOT 1997 Outstanding Highway Project – SR 273, Amtrak to Ogletown Interchange DelDOT 1992 Outstanding Highway Project, Route 7, Phase I
- Magna Cum Laude, Drexel University
- George W. Childs Drexel Award for Academic Achievement
- Mozino Blue and Gold Award for Service, Drexel University, 2011