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Impact Of Critical Path Method (CPM) Of Scheduling On On-Time Completion Of Transportation Projects

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IMPACT OF CRITICAL PATH METHOD (CPM) OF SCHEDULING ON ON-TIME COMPLETION OF TRANSPORTATION PROJECTS

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DEDICATION

I dedicate this work to my parents, Sk Shafi Ahmed and Shirin Akter, and to my beloved wife, Mishma. I thank them for believing in me, supporting through difficult times and continuous care.

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ABSTRACT

This study addresses the effectiveness of Critical Path Method (CPM) scheduling on project delivery. Specifically, the on-time completion of projects with and without a CPM schedule is explored. The paper uses data from 2,097 South Carolina transportation projects let after February 2008 and substantially completed by August 2015. The delay analysis uses the original contract completion date as well as the completion date adjusted by change orders. Chi-Squared tests are used to examine the relationship between CPM scheduled projects and delayed projects, and t-tests are used to compare the mean delay (in days) between CPM scheduled and unscheduled projects. The results of these tests indicate that both the fraction of delayed projects and the mean delay (in days) are larger in projects with CPM schedules. Several conjectures that explain these unexpected results are given. A nationwide survey was conducted to find out the viewpoint on CPM schedules of state Departments of Transportation(DOTs), resident construction engineers and contractors. The survey revealed that most state DOTs use CPM along with Gantt chart for scheduling and perceived complexity and risk are used to select projects for CPM schedules. Resident construction engineers indicated that delay before the start of work on the field do not impact the overall duration of the project. The contractors acknowledge the importance of CPM schedules but they sometimes fail to make most out of CPM schedules. The issues regarding selection criteria, enforcing and skilled person for CPM schedules are addressed in the study and recommendations are provided.

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CHAPTER 1: INTRODUCTION

1.1 Background and Problem Statement

Construction delays of transportation projects are one of the most recurring and critical problems facing state agencies. Several studies have assessed the efficiency of projects managed by State Departments of Transportation (DOTs) and the results show that only about half of the projects met their projected budgets and schedule. According to the study by Crossett and Hines (Crossett & Hines, 2007), the average on-budget project delivery is 46% over a five-year period (2001 – 2005), and in a follow-up study by Crossett and Schneweis (Crossett & Schneweis, 2011), the average is 47% over a ten-year period (2001 – 2010). The on-time performance is only slightly better at 53% (Crossett & Hines, 2007) over the five-year period and 55% over the ten-year period (Crossett & Schneweis, 2011). The delay in a construction project may affect the overall productivity of the project due to its adverse effects, such as cost escalation, poor quality of products, reduced productivity, late completion of work, disruption of work, and termination of contracts (Kaliba, Muya, & Mumba, 2009, Aibinu & Jagboro, 2002). In addition, delay affects all parties involved in the construction project, such as owners, contractors, consultants, etc. (Boland, 2007). Lastly, project delay on transportation projects affect nearby communities and the traveling public (Hugh, 2003).

The Critical Path Method (CPM) is the most popular tool for scheduling and planning in construction industry. Surveys conducted in 1974, 1990 and 2003 on CPM usage reveal an increasing trend (1974: 90%; 1990: 92.6%; 2003: 98.5%) of CPM utilization in the construction industry (Kelleher, 2004; Tovakoli & Riachi, 1990). CPM has grown in popularity over the years since its inception by DuPont in 1950 due to ease of use (Kelleher, 2004) and analytical simplicity compared to other scheduling methods (i.e. PERT) (Galloway, 2006). CPM is also a popular project management tool used in transportation projects managed by the DOTs. According to an on-line survey conducted as part of this study and information reported from the Alabama DOT's website, it was found that 65% to 75% of state DOTs specifies CPM as a requirement in their specification. Indeed, the popularity of CPM scheduling has grown so much since the fifties ('50s) that scheduling in the construction industry and use of CPM scheduling have become synonymous (Yates, 1993). In addition to detail planning and controlling of projects, CPM has also been used for estimation and bidding, claim analysis (Kelleher, 2004) and as well as risk management (Galloway, 2006). The reported benefits of using CPM in project management include improved planning, scheduling, controlling, minimizing disputes, time and cost saving and more control over risks and uncertainties.

Given that most transportation projects today are required to use CPM, this thesis seeks to address the following research question: *Is CPM scheduling effective in reducing delay for transportation projects?* To our knowledge, this is the first attempt to quantify the effectiveness of the use of CPM in managing project delay. On-time completion of projects is selected as measure of effectiveness for the study. This thesis also identifies the factors that are associated with project delay. The findings from this paper will help other state DOTs recognize the factors of delay in transportation construction projects. If the factors are known *a priori*, then special attention can be given to these causes to minimize their impact.

1.2 Scope of the Study

The scope of study is included in the following:

Transportation Project: All the project information was acquired from South Carolina Department of Transportation (SCDOT). All SCDOT construction contract types were considered for the study except design-build projects. Projects include:

- Paving (hot mix asphalt, concrete)
- Structures (bridges, drainage structures, sidewalks, gutters, guardrails)
- Paint and marking (epoxy pavement markings, raised pavement markers, thermal pavement marking)
- Sign and signal (highway signs, traffic signals)
- General (landscaping, other or mixed projects)

Analysis period: The projects that let after February 2007 and that were substantially completed on June 2015 were considered for the present study.

Geographical Extent: The present study considered all the projects in the analysis period from the seven (7) SCDOT districts.

1.3 Overview of the Study Approach

This study examines the impact of CPM schedules in reducing the time delay of transportation projects. To accomplish this, the study is conducted in two parts. The first part is to conduct the statistical analysis of the transportation project data acquired from SCDOT. The statistical analysis is performed in two steps. The first step is to examine the relationship between transportation projects with a CPM schedule and delay. Chi-square test of independence is used to examine the relationship. The second step is to compare the delay statistic (i.e. mean delay) for projects with a CPM schedule and unscheduled projects. In both, the statistical analysis delay is considered after original completion date and adjusted completion date. In the second part, survey on scheduling practices and on the use of CPM is performed. This part is also a conducted in two steps. In the first step, survey of the standard specifications for construction of the DOTs is performed to acquire information of current scheduling practices. In the second step, an online questionnaire survey of state DOTs, resident construction engineers and contractors is conducted to gather information on their experience and viewpoint of the impact and use of CPM schedules for transportation projects.

1.4 Organization of Thesis

This thesis is divided into six (6) chapters. Chapter 1 presents the research background and problem statement. It also explains the research needs as well as research scope and objectives. Chapter 2 presents an extensive literature review of the research. This chapter covers the growth, use, advantages, disadvantages, and success factors for CPM scheduling method. In addition to that, the chapter provides overview of project management software. The current practices in the state DOTs in construction is also discussed in this chapter. Chapter 3 describes the data collection and analysis method of the data. The data collection process includes acquiring information of transportation projects from South Carolina Department of Transportation (SCDOT). This chapter also describes the design of online questionnaire survey of DOT personnel, resident construction engineers and contractors. The results of the statistical analysis of the SCDOT transportation project data and questionnaire surveys are presented in Chapter 4. Chapter 5 illustrates the insights obtained from the research study. Chapter 6 presents an overall summary and conclusion for the statistical analysis results and surveys. This chapter also provided recommendations and limitations for the study. Survey results on standard specification of DOTs are presented in Appendix A. Detailed statistical analysis results are presented in Appendix B. Online questionnaire survey questions and results are illustrated in Appendix C.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Numerous research efforts have been published addressing the factors contributing to delay. Identification of delay factors in construction projects has been studied focusing on general construction projects (Chan & Kumaraswamy, 1996; Sambasivan & Soon, 2007), building projects (Assaf, Al-Khalil, & Al-Hazmi, 1995; Ogunlana, Promkuntong, & Jearkjirm, 1996), road construction projects (Kaliba, Muya, & Mumba, 2009; Mahamid, Bruland, & Dmaidi, 2012), and large projects (Assaf & Al-Hejji, 2005). Delay factors are also analyzed in various economic conditions in different countries (Al-Kharashi & Skitmore, 2009; Arditi & Gunaydin, 1998; Assaf & Al-Hejji, 2005; Doloi, Sawhney, Iyer, & Rentala, 2012; Kaliba, Muya, & Mumba, 2009; Mansfield, Ugwu, & Doran, 1994; Sambasivan & Soon, 2007). Some of the common causes for delay of transportation projects identified in the literature include financial difficulties in client organization, poor contract management, shortages of material or equipment, change orders from owner, poor site management and awarding contracts to lower bidder (Kaliba, Muya, & Mumba, 2009; Mahamid et al., 2012; Mansfield et al., 1994; Park & Papadopoulou, 2012). A study by Bordat et al. (Bordat, Mccullouch, & Labi, 2004) on the Indiana DOT transportation projects reported that the contributing factors for time, cost overruns and change orders are contract bid amount, difference between the winning bid and second bid, difference between the winning bid and the engineer's estimate, project type and location by districts.

Aibinu and Jagboro (Aibinu & Jagboro, 2002) categorized the effects of construction delay into six factors which include time overrun, cost overrun, dispute, arbitration and litigation and total abandonment. Santoso and Soeng (Santoso & Soeng, 2016) conducted a questionnaire survey on effect of delay and found that respondents have given larger weight on on-time performance relative to cost and quality. Different project management techniques are used to successfully execute projects.

2.2 Scheduling Techniques

Modern project management technique dates to the work of Harry Gantt who developed a graphical method for tracking projects with multiple tasks (Gantt, 1910). The shortcomings of a Gantt chart are that it does not show the interrelationships between the activities within a work sequence. In the 1950s, DuPont developed the Critical Path Method (CPM) to tackle the interrelationships of separate activities within a project schedule. Thus, Critical Path Method is a project management tool aim to make a project efficient. CPM breaks down the complex activities of a project into sequence of small activities or tasks associated with costs and resources. (Galway, 2004) defined CPM as network representation of activities with non-stochastic (deterministic) estimation of task duration. It facilitates the computation of critical path (set of tasks determine the project length). CPM encourages efficiency by optimizing the sequence of scheduled activities, or tasks, in a project. It is the essential part of the project for developing logic of the network and also for managing day to day project activities. It provides the direction required for success to the project. Another technique of project management was developed in mid of 1950s. The lack of project management tool in 1950s lead the US navy's Polaris programme officers to develop a new management tool named Programme evaluation and Review

Technique (PERT). The main difference from CPM in the method was embedded in calculation of the duration for each task. The novelty comes from introducing statistical calculation as oppose to deterministic time calculation. A probability distribution for each tasks were calculated with the help of expert engineers and three time estimates were reported: pessimistic time, optimistic time and most likely time (Galway, 2004; Klementowski, 1978).

2.2.1 Critical Path Method

Critical path method (CPM) scheduling is the application of logic relationship and precedence between activities. This procedure determines the activities that are critical works in a schedule. Critical works are required to perform on time to manage the project successfully. On the other hand, the noncritical activities have float. The sequence of connected critical activities establishes the anticipated project duration.

The popularity of CPM method of scheduling gained through two means, enhancement of computation through computers over time and loss of interest of user in PERT scheduling method. One of the reasons CPM preferred over PERT was due to its analytical simplicity (Galway, 2004). The use of CPM method of scheduling has grown over the years since its inception as commercial software since 1950s. Three surveys were conducted to answer the question on how Engineering News Record's (ENR) top 400 companies use CPM. The first survey was conducted in 1974 by Edward Davis , second one in 1990 by Tovakoli & Riachi, and a third survey focusing the same objective took place in 2003.The first survey revealed that 90% of the companies use CPM while in the second it was 92.6% and it increased to 98.5% in 2003. The survey data show an increasing trend in use of CPM for project management by the companies. The increase in usage of CPM schedule for project management is due to the development of certain technologies in mid of 1980s that facilitated the growth (Kelleher, 2004; Liberatore, Pollack-Johnson, & Smith, 2001). The popularity of CPM scheduling grew so much that the scheduling in construction industry and use of CPM scheduling became synonymous (Yates, 1993).

CPM schedules are used for many reasons in different types of companies. The effective use of CPM schedules as Galloway (Galloway, 2006) and Hildreth and Munoz (Hildreth & Munoz, 2005) pointed out are as follows:

- *Project time related works:* predicts project completion date and time window for activities, evaluate time impact changes to assess time-base claims.
- *Cost management:* helps managing money by predicting cash flows, avoid liquidate damages, compute progress payments.
- *Coordination and communication:* coordination of subcontractors, client-supplied information.
- *Conflict resolution:* helps addressing conflicts among trades, mitigate supply-demand conflicts.
- *Effective project control tool*

In addition to these usages, the survey conducted by Galloway (Galloway, 2006) adds to the use of CPM scheduling for estimation and bidding, planning of work prior to construction and operation and maintenance of the projects. (Kelleher, 2004) indicated that the use of CPM also varies with the size of the company. Larger companies are more likely to manage complex projects than smaller companies. Kelleher (Kelleher, 2004) showed that large companies are more successful user of CPM method than medium or small sized companies.

The advantages of CPM scheduling method over bar charts are that it can show detailed breakdown of activities and also relationships among activities. A CPM schedule can also be loaded with resources. The resources can be of various forms, such as manpower, costs. Another key advantage of CPM is that it can utilize multiples calendars in the schedules which helps in managing projects. The use of CPM in scheduling improves planning, scheduling, controlling, estimating and bidding, communicating, and understanding of projects. It also minimizes disputes between contractor and owner, reduces delay and saves time and cost of the project. Using CPM also trains people in the company who have the potential to become a project manager in the future. (Kelleher, 2004) indicated that all large companies perceive an economic benefit in using CPM schedules.

Though CPM generally viewed as an effective tool for project management, the surveys of 2003 (Kelleher, 2003) and 2006 (Galloway, 2006) data revealed some of the disadvantages faced by the project stakeholders and companies. Most of the contract require a CPM schedule from the contractor. It found that contractors sometimes take advantage of this privilege and perform negative analysis. One of the reasons to abuse the scheduling is due to retaliation (Mccullough, 1999). In the survey in the 1990 of ENR' top 400 companies, input and output abuses by the contractor were regarded as the biggest disadvantages of CPM. Galloway's (Galloway, 2006) on-line survey found this to be a unsolved issue as owners complained about the manipulation of schedule in the program by the contractor’s. The common disadvantages found in both surveys of 1990 and 2006 were excessive work and time requirement for input, constant updating for reliability and CPM acts as ineffective communication tool to connect field personal. In addition to those 2006 survey points out that requirement of skilled personal for operation as the software became more sophisticated as another disadvantage of CPM. In the survey of 1990 lack of support from the field people and lack of support from project manager were attributed as the reason for unsuccessful use of CPM.

Success of CPM as a project management tool depends upon efficient utilization of the method in projects. Co-ordination on each level of organization is necessary for a successful project. In the survey of Engineering News Record’s (ENR) top 400 companies in 1990 (Tavakoli and Riachi, 1990), the successful users of CPM scheduling pointed out that support from project manager, from top managers and good computer programs as the key reasons for the success. Other success factors indicated by (Kelleher, 2004) that the correct use of the technology (i.e. software) for well-maintained, updated and reliable schedules. (Galloway, 2006) pointed out another important success factor for CPM, the experience (or lack of) of the scheduler and recommends training programs for scheduling personnel.

2.3 Overview of Project Management Software

There are many available tools for the implementation of scheduling technique for project management. The choices include customized forms, checklists and the use of commercial software. Some of these choices are more complex and requires skilled persons to perform. The advancement of computing enhanced the capabilities of these tools but it also made it complicated to implement. The commercial software such as Primavera products is used for complex project while simpler tools include Microsoft Excel, Microsoft Project. The state DOTs also use AASHTOWare project SiteManager to manage its projects. The choice of which software to use depend upon perceived project complexity, risks, and project size and duration. A brief description of some of the common software used in project management.

AASHTOWare® Project SiteManager

The AASHTOWare project management software is used by the DOTs of 50 states and also Canadian transportation agencies. The key features of this software are easy to comply with Federal Highway Administration regulations, AASHTO standards and industry best practices (AASHTOWare, 2017). The software is also flexible to accommodate differences of state-to-state in construction standards. The SCDOT uses the SiteManager software to manage construction contracts and use as a repository of contract records. It also keeps the record the detailed work information, resource used, and change orders.

Microsoft Products

Bar charts are a common technique for scheduling and is well used in small and short duration projects. Microsoft excel can be used to show the activities and bar charts. These bar charts show the dates and duration of each activity. However, bar charts fail to show the breakdown of activities and relationship between activities. Hence, Microsoft project is used where more details to be presented than only the bar charts. The advantage of using this software is that it can show the relationship between the activities. Another feature for Microsoft project is that it can also determine the critical path of the project. The cost of scheduling in Microsoft project is lower than Primavera. The disadvantage is that it is not well suited for complex projects and for implementing extensive analytical techniques (Liberatore,2001).

Primavera Products

Primavera software is more appropriate for scheduling complex projects and to apply more analytical technique in scheduling. The survey of Galloway (Galloway, 2006) revealed that, 65% contractor s indicated that they prefer Primavera software. There are various types of packages available from Primavera. One can choose any one of these depending upon the usage level.

2.4 Current Practice of the State DOTs

To find out the current practices, the online standard specifications for construction of each DOTs was surveyed. This survey provides information on the methods and preferred software used by the DOTs to manage their projects. The focus of the survey grouped into five categories: techniques for analyzing and displaying schedules, type of projects schedules, preferred software for scheduling, type of payment method for scheduling and requirement of appointed scheduler. The categories and unique values to measure current practices from the survey of standard specifications are presented in Table 2.1.

Rowings (Rowings, Harmelink, & Rahbar, 1993) conducted a statewide survey of the state DOTs to gather information of the scheduling practices. Thirty-six (36) DOTs responded to the survey and some of the key highlights of the survey are presented here.

Calculation of project duration was conducted by experience, type, size of the project (44%), past history of the projects (22%) and only 4% used CPM for the calculation. Forty-seven (47%) responded that DOTs do not require a schedule specification. The two most popular method of scheduling at that time were CPM and bar charts. In regard to information loading with schedules, most of the DOTs did not request any cost or resource loaded schedules.

Table 2.1 Focus groups for standard specifications for construction of DOT

Scheduling techniques	CPM requirement	Preferred software	Payment method	Appointed scheduler
1. Only CPM	Yes	1. Primavera Product	Incidental to work item	Yes
2. Only Bar chart	No	2. MS Project	Payment for the item	No
3. CPM and Bar chart		3. SureTrak		
4. CPM and other techniques *(Other includes activity chart; Written narration etc.)*		4. Asta Powerproject 5. Form(s) prescribed by department 6. Any computer developed schedule		

The survey results of the standard specifications of each DOT is presented in Appendix-A. This reveals that most of the DOTs require scheduling in most of their projects. The level of scheduling may differ from state to state. For example, California DOT requires three levels of scheduling depending upon the workings day and bid amount of the projects. In all cases it requires a CPM schedule but the specifications are different for each level.

Depending upon the level of effort for scheduling DOTs use different scheduling techniques. Most common techniques employed are bar charts and CPM. Other techniques include written narrative, activity chart, any network diagram etc. Some DOTs also use customized charts. For example, Texas DOT uses TxDOT standard spec item 8.5 for monitoring projects.

In case of scheduling tools for CPM schedules, bar charts and CPM are most common among the state DOTs. Some DOTs also require written narrative along with these schedules, for example Kentucky DOT.

Payment for schedules are important parameter for measuring whether the CPM schedules extensively used in the project or it is just a specification requirement. The state DOTs most often include the payment for schedule as incidental to any work item. But some DOTs explicitly pay for CPM scheduling. Some DOTs request a dedicated scheduler for a project. This indicates the emphasize of the that DOT on CPM scheduling.

2.5 Chapter Summary

Project management literature have examined numerous causes and effects of project delay. The use, advantages, disadvantages, and adaptation of CPM scheduling in project management have also been studied. Most of these results are from the surveys of owners, contractors, and state DOTs. But to the authors knowledge, no study has investigated the use of Critical Path Method (CPM) schedules as a factor in on-time project completion. This study aims to investigate in this unexplored gap.

`CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter discusses the framework and methods used for analyzing the impact of time overrun on the transportation projects. The methodology includes selection of independent and dependent variable, preliminary descriptive statistics, chi-square test of independence and two sample t-tests. It also discusses the method of conducting online questionnaire survey to find out the impact of using CPM in projects.

3.2 Selection of Variables

To find the general trend in the data, a graphical trend analysis of the datasets for the study is conducted. Project type, project size, project duration, and project location are the independent variables and the time delay is considered as dependent variable. The variable project type and project location were already categorized in the provided datasets. The independent variable project size was categorized into three levels: small, medium, and high. The other independent variable project duration was also categorized into three groups: short, medium, and long. The details of categorizing the data by project size and project duration are presented in section 3.5.

3.3 Descriptive Statistics and Statistical Analysis

The study aims to find out the impact of the CPM method of scheduling on time delay of transportation projects. The descriptive analysis of the datasets reveals insights on this objective. Simple descriptive graphs are used to characterize the data by independent variables. Single and grouped bar plots of independent variables and frequency table provide information to understand the data. In order to measure the relative significance of independent variables descriptive figures such as grouped bar plots are used.

The statistical analysis is focused on determining two aspects of the data. The first one is to examine the relationship of the variables. The second one is to determine the difference in statistics (i.e. mean) from two populations. The Chi-square test of independence is used to examine the relationships between variables and t-test is used to measure the difference in statistics from two samples. The overall framework of the statistical analysis is shown in Figure 3.1

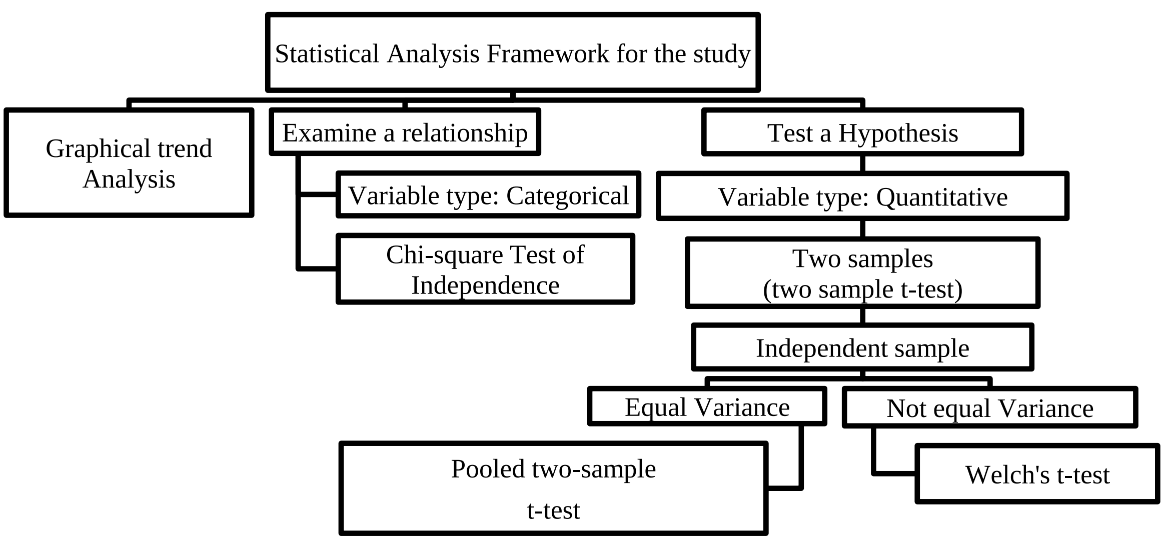

Figure 3.1 Statistical Analysis framework for the study

3.3.1 Chi-square test of independence

Chi-square test of independence is used to examine the relationship between categorical variables**.** Chi-square test (also known as Pearson Chi-square test) is one of the most commonly used non-parametric test. The advantage of using a non-parametric test lies in its assumptions. The assumptions for the Chi-square test are:

- Distribution of the sample data does not follow any specific distribution (distribution free test).
- Sample data is collected from two categorical variables (i.e. sample data can be distributed into distinct categories).
- The data in distinct categories should be in frequencies or counts.
- The categories of variables are mutually exclusive.
- The frequency of expected value in any cell of the contingency table of categories should be 5 or more in at least eighty percent of the cells. In addition to that, expected value in any cell should not be less that one.

A Chi-square test of independence is conducted by determining the distinct category of variables for the test. The count or the frequency from the sample data are divided into distinct categories of variables. Thus, a contingency table of observed values is constructed from the sample data. The frequency or count on each cell of the contingency table should follow the assumption of the Chi-square test state above. Then Chi-square test is performed to determine if the categorical variables are related (i.e. associated) to each other. The hypothesis tested in the Chi-square test of independence is as follows:

$H_0: In\ the\ population, there\ is\ no\ relationship\ between\ the\ categorical\ variables.$

$H_a: In\ the\ population, there\ is\ relationship\ between\ the\ categorical\ variables.$

To perform this test, first the two categorical variables are summarized in the form of a contingency table as illustrated below

	Second categorical variable			
First categorical variable	**1**	**.**	***j***	**Total**
1	C_{11}	.	.	R_1
I	.	.	.	R_i
Total	C_1	.	*Cn*	*n*

The Chi-square test statistics is used to test the hypothesis. The formula to calculate the chi-square test statistics is:

The χ^2 test statistic is calculated as follows (*25*).

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c}\frac{(O_{ij} - E_{ij})^2}{E_{ij}} \tag{1}$$

where,

$\chi^2 =$ the test statistic

$O_{ij} =$ the observed count in cell (*i*, *j*)

$E_{ij} =$ the expected count in cell (*i*, *j*)

r = number of rows

c = number of columns

The expected count in each cell is calculated as follows.

$$E_{ij} = \frac{R_i C_j}{n} \tag{2}$$

where,

R_j and C_i are the row and column totals, respectively.

The degree of freedom is calculated using the following formula:

df = (*r*-1)(*c*-1) ; where *df* = degree of freedom (3)

The chi-square test statistics finds the answer to the question whether the expected value differs significantly from our observed value. For the decision making on the null hypothesis a level of significance (α) is set and *p-value* is calculated from the chi-square statistics by the formula P($\chi^2 > \chi^{2*}$) with degrees of freedom = (number of rows - 1)*(number of columns - 1). If the *p-value* is less than 'α' the null hypothesis is rejected.

The chi-square test is conducted to find if there is any association between the depended variable (i.e. delay, cost overrun) and the use of CPM for schedules. Both the variable is treated as binary variables. For example, the binary variable 'delay' is classified as whether there is a delay (defined as '1') or not (defined as '0'). Again, for use of CPM for schedules, whether CPM schedules used for the project or not. Two-way contingency table is created using the two categorical variables. The null hypothesis tested is that there is no relationship between dependent variable and the use of CPM for schedules. The test is conducted for each independent variable (project type, project size, project location). The results of Chi-square test of independence are presented in Appendix-B, Table 4.8.

3.3.2 t-test

The t-test is conducted to compare two means of independent variable to find out whether these means are significantly different from each other. This test is also known as two sample t-test. The assumptions of two sample t-test are:

- The data is continuous.
- The data follows normal probability distribution.
- The two samples are independent.
- The variances of the two populations are equal.

The assumption of variance in the two-sample t-test determines which t-test to use for the comparison of the means of the samples. If the variance of the two populations are equal (Homogeneous variances) pooled two-sample t-test is used. If the variances are not equal (Heterogeneous variances) Welch's two sample t-test is used.

The two independent samples are taken for each independent variable. To test the homogeneity of variance the F-test for variance is used to test the homogeneity of variance of the samples. The hypothesis for the F-test is:

$$H_0: The\ variances\ of\ the\ two\ populations\ are\ equal. (\ \sigma_1^2 = \ \sigma_2^2)$$

$$H_a: The\ variances\ of\ the\ two\ populations\ are\ not\ equal. (\ \sigma_1^2 \neq \ \sigma_2^2)$$

The result from the F-test for homogeneity indicates whether to conduct the pooled two sample t-test or Welch's t-test. The null hypothesis tested in both the cases is as follows:

$$H_0: There\ is\ no\ difference\ in\ means\ of the\ two\ samples\ (\ \mu_1 = \ \mu_2)$$

$$H_a: There\ is\ difference\ in\ means\ of the\ two\ samples\ (\ \mu_1 \ \neq \mu_2)$$

The equation of test statistics depends upon which t-test is conducted. The equation for test statistic of the pooled sample t-test is:

$$t^* = \frac{\bar{x}_1 - \bar{x}_2}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

Where, $\bar{x}_1$ = mean of sample 1

$\bar{x}_1$ = mean of sample 2

n_1 = sample size of sample 1

n_1 = sample size of sample 2

s_p = Common standard deviation = $\sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{df}}$

s_1^2= variance of sample 1

s_2^2= variance of sample 2

df = degrees of freedom = $n_1 + n_2 - 2$

The equation for test statistics of Welch's t-test and the degrees of freedom is slightly different form the above method and is as follows:

$$t^* = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

With df = degrees of freedom = $\frac{(n_1-1).(n_2-1)}{(n_2-1).C^2 + (1-C)^2(n_1-1)}$ and $C = \frac{s_1^2/n_1}{\frac{n_1^2}{n_1} + \frac{n_2^2}{n_2}}$

The test statistics finds the answer to the question whether the means of sample 1 significantly differs from the mean of sample 2. For the decision making on the null hypothesis a level of significance (α) is set and *p-value* is calculated from the test statistics by the formula P (t >t^*). The degrees of freedom to calculate the p-value is associated the type of two sample t-test is conducted on the samples. If the *p-value* is less than 'α' the null hypothesis is rejected. Generally, in engineering application the 'α' value is set to 0.05 for comparison of means of samples using two sample t-test.

The t-test is used to find out whether the depended variable (i.e. time delay, cost overrun) significantly differed by the use of CPM schedules. The two samples were taken from the unscheduled projects and projects scheduled by CPM method. Then the samples were categorized by independent variable (i.e. project type, project size and project location). The dependent variables were quantitative variables acquired from the SiteManager database. The null hypothesis tested is that there is no significant different in dependent variable when using CPM method for scheduling the projects. The results of t-test presented in Appendix-A, Table 4.9**,** Table 4.11**.**

3.4 Survey of Use of CPM

The aim of the survey is to understand the methods used by the state agencies to manage time delay of their projects. The survey was conducted in two steps. The first step was to conduct online survey on the standard specifications for construction of each agency to find out the current practices of their project management. The second step was a questionnaire survey to acquire information on the effectiveness of Critical Path Method (CPM) for scheduling. In addition to these steps, phone interviews of selected DOT personnel managing projects were conducted to better understand the ins and outs of the CPM use in practice.

3.4.1 Survey methodology

The online questionnaire survey was conducted to find the effectiveness of CPM schedules for managing time delay of the projects. The purpose of the survey was to gather information about selection criteria for CPM schedule for projects, contractual requirements of CPM, preferred software, evaluation of contractor on CPM use, impact of CPM schedules on project time extension, and different practices and approaches of project management in transportation projects. The targeted participants of the survey were the DOT personals, the Resident Engineers and contractors working on DOT projects. Online questionnaire was created to conduct the survey for each category of participants.

Three separate online surveys were created for DOT personnel, Resident Construction Engineers and contractors. All the questions were crafted to gather information from the participants to meet the study and were distributed to other DOT personnel, RCEs and contractors by SCDOT.

Table 3.1 Topic focused on the survey for DOT headquarter personnel, Resident Construction Engineer and Contractors

Topic focused on the survey	DOT headquarter personnel	Resident Construction Engineer	Contractors
Scheduling technique employed/preferred	Q2, Q9		Q6
Selection of projects for CPM schedule	Q3	Q2	
Contract requirements / specifications of CPM scheduling	Q4, Q5		Q2
Scheduling software used/preferred	Q6, Q11, Q12, Q13,		
Decision making based on CPM schedules		Q3	Q4
Storage and Access of schedule database	Q8, Q14, Q17		
Effort made to follow CPM schedule		Q4	
Use of CPM schedule (planning, claim analysis, revisions of CPM etc.)	Q15, Q16	Q5, Q10	Q3, Q7, Q8
Project extension / Delay associated with CPM schedule		Q6, Q7, Q8, Q9	
Schedulers requirements and tasks			Q9, Q10, Q11
Cost of CPM application			Q5
Value of CPM for success of the company			Q12

The breakdown of the questions in the survey for DOT personnel, resident engineers and contractors are shown in Table 3.1. There were seventeen questions for each DOT personnel which is divided into six areas: (1) Selection for projects for CPM, (2) Contract specifications for CPM, (3) Scheduling techniques use, (4) Scheduling software preference, (5) Scheduling database storage and access, and (6) Different usages of CPM schedule.

For resident engineers, there were ten questions which focused on five areas: (1) Selection of projects for CPM schedule, (2) Decision making using CPM schedule, (3) Different usages of CPM schedule, (4). Delay associated with CPM schedule, and (5) Assessment of contractors' effort. The survey questionnaire for contractors includes eleven questions to focus on (1) Contract specification for CPM, (2) Scheduling software preference, (3) Decision making using CPM schedule, (4) Different usages of CPM schedule, (5) Scheduler appointment and tasks, and (6) Cost and success of CPM use areas. The first question of each survey is excluded in the survey matrix of Table 3.2 because it contains information about respondent's identity.

The participants of the survey responded to the online survey through web-based survey tool, Google Forms. The survey is shown in Appendix-C And the results of analysis are discussed in chapter 4 and 5.

3.4.2 Phone Interviews

Phone interviews were planned for other DOTs to verify information and understand the schedule practices in other States. The results from the survey of DOTs of their standard specifications and respond from the online questionnaire survey were analyzed in order to select five state DOTs for phone interview. These selected DOTs for phone interview had well planned and organized standard specifications that provided the indication of good and effective practices of CPM schedule for their projects. Table 3.3 shows the criteria used for selection from standard specifications.

Table 3.2: Lists of DOTs for phone interviews

State DOT	Scheduling method Required	Preferred software	Payment method	Designated scheduler
California (CALTRANS)	CPM	Primavera P6	Paid for CPM	
Maryland (MDOT)	CPM		Paid for CPM	Yes
Texas (TxDOT)	CPM, Bar Chart		Incidental to work Item	Yes
Utah (UDOT)	CPM	Primavera P6	No payment (Contractor's Obligation)	
New York State (NYSDOT)	CPM, Bar Chart	Approved by Department (currently Primavera P6)	No payment (Contractor's Obligation)	

Among the five state DOTs, three of them responded to our online survey. These DOTs provided interesting response regarding selection of CPM schedule to use in their projects and use of CPM schedule for different complexity and duration levels.

3.5 Data Description

All the data regarding projects for analysis of schedule impact on delay were collected from the information provided by the SCDOT. The timeframe of the projects is approximately eight years: projects let after February 2007 to June 2015. All the projects reached substantial completion data within this timeframe. There were 2,097 projects in the period of analysis.

SCDOT uses two types of software for the purpose of project management. The AASHTOWARE Project SiteManager® computer application is used to manage information regarding contracts. The dataset contains general information of SCDOT projects, change order information, Daily Work Report (DWR) and item used in projects. The data for time overrun analysis is recorded in the general information table of the provided dataset. The SiteManager dataset provided by SCDOT is in Microsoft Access® format. The codes used in the dataset are indicated in Table 3.3.

Table 3.3 Raw project data description in SiteManager provided by SCDOT

Variable Name	Description	Information type
CONT_ID	Unique code identifying each project	Project
FED_ST_PRJ_NBR	Unique code for funding management purposes	Project
LEV3_OFFICE_NBR	Engineering district that manages the project	Project
LEV4_OFFICE_NBR	Resident Construction Engineer (RCE) office	Project
VEND_ID	ID for prime contractor	Project
TOT_BID_AMT	Original bidding amount for the project	Cost
NET_C_O_AMT	Total change order amount	Cost
Total_Paid	Total amount paid	Cost
TTBID	TOT_BID_AMT plus NET_C_O_AMT	Cost
NTP_Date	Notice to proceed date	Time/Dates
Adj_Comp_Date	Adjusted completion date (original completion date plus time change order)	Time/Dates
CompDate	Substantial completion date	Time/Dates
Letting_Date	Date the project was let	Time/Dates
WRK_T	Type of project (i.e. Bridge, surfacing, painting etc.)	Project
ORGC_Date	Original completion date when the project was let	Time/Dates
DESC1	Brief description of the project	Project
LOC_DESC1	Brief description of the project location	Location

From Table 3.3 four types of information (e.g. project related, time related, cost related, and project location related) for a project were separated from the database. The information type and their related fields is also shown in Table 3.3.

Time related information includes letting date, notice to proceed date, original and adjusted completion date and substantial completion date for each project. The total bid amount and net change order amount data were retrieved from the dataset for cost related analysis. For geographical information of the projects, SCDOT districts were extracted from the database. There are seven SCDOT districts which are marked with the numbers from 1 to 7 in Figure 3.2. These district numbers are provided in the location information field (LEV3_OFFICE_NBR) to retrieve the geographical information of the projects.

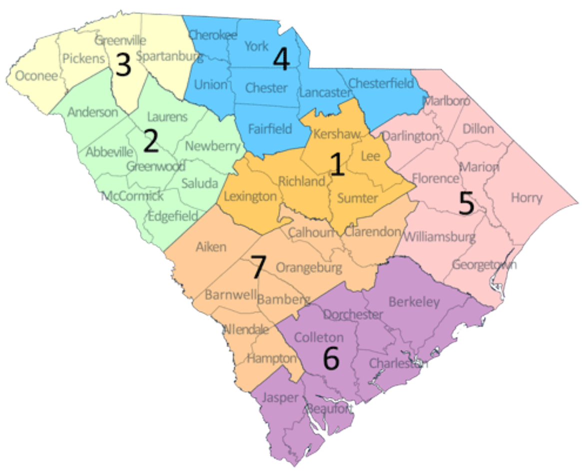

Figure 3.2 SCDOT engineering districts
(Source:http://www.scdot.org/inside/engineering_directory.aspx accessed on 25 March, 2017)

There is a total of 2,097 projects in the SiteManager database, which are divided into 16 different project types defined in Table 3.4. The type of project information is recorded in the WRK_T field in the SiteManager database table.

Table 3.4 Description of different types of projects in the SiteManager database

Type	Description
ASPT	Surface treatment
BRDG	Bridge
BRPT	Bridge paint
CGSW	Curb, gutter, side walk
DRST	Drainage structure
GDRL	Guardrail
GNRL	Projects are spread between several different categories, such as widening projects but without any dominating project type like HMAS or ASPT in terms of percentage of project cost. The project team refers to this type of projects by general construction projects.
HMAS	Hot-mixed Asphalt paving
LDSC	Landscaping
PCCP	Concrete pavement
PMEP	Epoxy pavement marking
PMPT	Pavement marking
PMRP	Raised pavement Markers
PMTH	Thermal pavement marking
SGNL	Traffic signal
SIGN	Roadway signs

The primavera software is used by the SCDOT for planning, managing and executing its projects. The primavera database contains information regarding Critical Path Method (CPM) schedules of the project. The "OBSPROJ" table contains information regarding the EPS structure and the schematic diagram of different levels of EPS is shown in Figure 3.3. The Enterprise Project Structure (EPS) shows that all the projects in Primavera are contained under Resident Construction Engineer (RCE) level.

The Primavera database was provided in a SQL format. The "PROJECT" table of the primavera database contains records of all projects scheduled using this software. The

“PROJWBS” table contains each of the projects in “PROJECT” table with additional information of update.

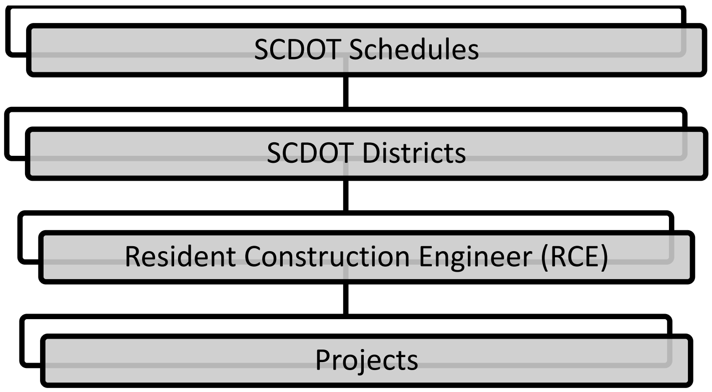

Figure 3.3 Enterprise Project Structure of Primavera database

3.5.1 Database Development

The extracted information from the SiteManager and Primavera database are merged together to produce a completely new database for analysis. The SiteManager and Primavera datasets were joined using the unique project identifier “CONT_ID” in SiteManager and the “proj_short_name” field in the Primavera table “dbo_PROJECT”. The data items in the database are listed in Table 3.5.

For the analysis of project delay following variables are used:

- **CO_Delay -** Time delay (in days) measured in terms of number days beyond adjusted completion date, only for projects with a CO_delay > 0
- **TT_Delay -** Time delay (in days) measured in terms of number of days beyond original completion date, only for projects with a TT_delay > 0

Table 3.5 Database development and variables calculated

Data item	Database	Variable code	Meaning
Project related	SiteManager	CONT_ID	Unique identifier of the project
		TYPE	Category of the type of the project Code used in Table 5.3
	Primavera	PROJ_SHORT_NAME	Unique identifier of the project
		PROJ_ID	Unique identifier of the project
		WBS_SHORT_NAME	Title of the project
Time related	SiteManager	LET_DT	Letting date of the project
		NTP_DT	Notice to proceed date
		ORGC_DT	Planned completion date of the project at award
		ADJ_COMP_DT	Adjusted completion date of the project after change order
		COMP_DT	Substantial completion date of the project
		TT_DELAY	Delay after planned completion date; (COMPDATE – NTP_DATE)
	Calculated	CO_DELAY	Delay after adjusted completion date; (ADJ_COMP_DATE – NTP_DATE)
		TT_CODE	1, if there is TT_DELAY > 0; 0, otherwise
		CO_CODE	1, if there is TT_DELAY > 0; 0, otherwise
		TOT_BID_AMT	Total bid amount (USD) at the time of contract award
		NET_CO_AMT	Net change order amount (USD) for the project
Cost related	SiteManager	TTBID	Total bid amount after incorporation change order
		LEV3_OFFICE_NBR	SCDOT districts as in Figure 5.1
		TASKS	Number of tasks associated with each project

Location related	SiteManager	SSP_CODE	1, if there is payment item for schedule; 0, otherwise
Schedule related	Calculated	SSPRIM_CODE	1, if the project has a real schedule in Primavera; 0, otherwise
	SiteManager	SST_CODE	1, if there the has an entry in Primavera for schedule; 0, otherwise

The Primavera database contains projects that do not have a CPM schedule. Observations from the "OBS" table in the Primavera database show that under each Resident Engineer (RE), there are some projects that are marked as "No CPM". Also, some of the project titles (WBS_SHORT_NAME) indicate that these projects do not have a CPM schedule. These projects are identified by using the following criteria: -

i. The projects contained in the "No CPM" or "No CPM Reqd" level in the Primavera database.
ii. Indication of a non-real CPM schedule activities: Projects that have only "payout" or "cash flow only" or "estimate only" activities.
iii. Indication of a non CPM schedule: The title of the project (WBS_NAME in "PROJWBS" table) contains phrases: "Non CPM" or "non cpm schedule" or "NO CPM Required".

The above criteria are used to refine SST projects. Projects that fall into the above criteria are excluded from the SST projects and then further categorized all the projects as follows: -

- **SSPRIM** – all the projects in Primavera with real schedule. These projects are defined as SST projects that do not fall into criteria (i), (ii) or (iii).

- **SSNULL -** all the projects in SiteManager that are not SSPRIM.

To measure the effectiveness of the use of CPM on the delay of SCDOT projects in terms of project size, the projects are categorized into three groups by total contract bid amount (in USD in the corresponding year of the project in the analysis period):

- Small projects: Total contract bid amount between $0 to $ 360,000.
- Medium projects: Total contract bid amount between $360,000 to $1,000,000.
- Large projects: Total contract bid amount greater than $1,000,000.

Again, to measure the effectiveness of the use of CPM on the delay of SCDOT projects in terms of project duration, the projects are categorized into three groups by original duration of the projects (in months):

- Short projects: original duration of the project less than 6 months
- Medium projects: original duration of the project between 6 to 12 months
- Long projects: original duration of the project more than 12 months (1 year)

3.6 Chapter Summary

This chapter discussed the framework, methods and underlying assumptions of statistical analysis to understand the impact of use of CPM technique in projects for project delay. The methodology used in statistical analysis included examining relationship of categorical variables by Chi-square test of independence and hypothesis test by students' t-test. In addition to that, the process of two-step surveys and phone interviews are also discussed. First step of survey was conducted to gather information from standard specifications for construction of state DOTs for the current practices of CPM used in managing their projects. Second step was to conduct an online survey of DOT personnel, Resident Construction Engineers and contractors about the use of CPM in their projects. Phone interviews were also conducted for five state DOT personnel to gather information about their practices and improve SCDOT scheduling techniques.

CHAPTER 4: FINDINGS

4.1 Introduction

This chapter describes the findings obtained from online questionnaire surveys and the statistical analysis on transportation projects from SCDOT. It provides the basic information describing general characteristics of the project data obtained from SiteManager and Primavera database. A detailed description of time delay classified by various categories used in the statistical analysis gives an explicit overview of the variable. The dependent variable, time delay, is expressed both in terms of original completion date and adjusted completion date. The chapter also presents the survey results from the online questionnaire surveys. Survey information reveals the viewpoint of the survey participants on CPM method of scheduling in the transportation projects.

4.2 Descriptive Statistics

Table 4.1 shows the distribution of projects by project types. It shows that the majority of the projects in the SiteManager database are either HMAS (48%) or GNRL (14.5%). Table 4.1 also shows that in the Primavera database slightly more than half of the projects have a CPM schedules (SSPRIM: 55.22%). The paint and marking projects (BRPT, PMEP, PMPT, PMRP, and PMTH) and sign and signal projects (SGNL, SIGN) do not generally use CPM. This is also true for other project types such as guardrail (GDRL), drainage structure (DRST) and landscape (LDSC). Based on the results from

Table 4.1, it can be concluded that certain types of projects are more likely to have a CPM schedule.

Table 4.1: Distribution of SiteManager Projects, SST Projects and SSPRIM Projects by Project Types

Type	SiteManager	Entry in Primavera (SST)	Valid CPM schedule projects (SSPRIM)
HMAS	1,007	833	764
GNRL	304	242	195
CGSW	153	107	42
PMTH	108	62	4
ASPT	102	63	52
BRDG	98	83	77
PMRP	89	41	1
GDRL	85	13	2
SGNL	47	22	8
PMEP	21	10	0
PMPT	21	10	0
PCCP	14	12	8
DRST	13	7	2
LDSC	13	7	1
SIGN	12	6	2
BRPT	10	4	0
Total	2,097	1,522	1,158

Table 4.2 presents the distribution of projects by SCDOT districts (3 projects in the data were not assigned a district). The average number of projects in each district is 299. The district with most number of projects is district 5 with 352 projects. The number of projects for each district range from 250 to 352. It can be concluded that the number of projects is reasonably uniform across districts. All the districts use CPM schedules for more than half of its projects except for District 7. The district that uses CPM schedules for majority of their projects than other districts is District 2 (174 out of 287: 60.6%) followed by District 5 (209 out of 352: 59.4%).

Table 4.2 Distribution of Projects by Project SCDOT districts

Districts	Total number of Projects	Total number of SSPRIM Projects
1	333	193
2	287	174
3	283	149
4	289	168
5	352	209
6	300	157
7	250	108
Total	2,094	1,158

Table 4.3 shows the distribution of the projects by project size (large, medium and small). Each group contains about the same number of projects. The last column in Table 4.3 shows the number of scheduled projects in each category.

Table 4.3 Distribution of Projects by Project Size Groups

Project size Groups	Total number of Projects	Total number of SSPRIM Projects
Small Projects	702	206
Medium Projects	670	382
Large Projects	725	570
Total	2,097	1,158

Table 4.4 shows the distribution of projects by project duration. Long projects have larger fraction (286 out of 439: 65.2%) of projects than other two types of projects (short: 43.41% and medium: 55.2%).

Table 4.4 Distribution of Projects by Project Duration Groups

Project duration Groups	Total number of Projects	Total number of SSPRIM Projects
Short Projects	364	158
Medium Projects	1,294	714
Long Projects	439	286
Total	2,097	1,158

4.3 Impact of CPM Schedule on Project Delay

Using the transportation project data described above, the relationship between project delay and use of CPM schedules are evaluated. In addition to using the TT_Delay and CO_Delay variables for delay analysis, the following variables are also used to measure project delay:

- nCO_Delay – Number of projects with a CO_Delay delay greater than zero.
- nTT_Delay – Number of projects with a TT_Delay delay greater than zero.

Table 4.5 Impact of Using a Critical Path Method (CPM) Schedule on Project Delays by Project Type

Project Type	Total number of projects	Number of projects delayed after original completion date (nTT_Delay)		Number of projects delayed after adjusted completion date (nCO_Delay)	
		Delayed SSPRIM	Delayed projects	Delayed SSPRIM	Delayed projects
ASPT	102	18	38	10	20
BRDG	98	48	58	11	13
BRPT	10	0	5	0	1
CGSW	153	19	64	6	23
DRST	13	1	6	0	3
GDRL	85	2	63	0	3
GNRL	304	108	161	27	39
HMAS	1,007	423	506	113	153
LDSC	13	1	10	0	0
PCCP	14	2	6	0	0
PMEP	21	0	11	0	9
PMPT	21	0	6	0	2
PMRP	89	0	35	0	14
PMTH	108	1	69	0	32
SGNL	47	5	29	1	5
SIGN	12	1	8	0	2
Total	2,097	629	1,075	168	319

•

Table 4.5 shows the total number of SSPRIM projects that were delayed versus the total number of projects that were delayed in terms of nTT_Delay and nCO_delay, respectively. The results indicate that more than half (nTT_Delay: 629 out of 1,075, 58.51% and nCO_Delay: 168 out of 319, 52.66%) of the delayed projects have a CPM schedule. The results also indicate that fewer scheduled projects have delay after considering the impact of change orders.

Figure 4.1 and Figure 4.2 show the impact of having a schedule on the risk of project delay. Figure 4.1 shows that in the dataset, having a schedule was not effective in reducing the fraction of delayed projects for most project types. In fact, the project types that have a significant number of projects (i.e. HMAS, GNRL) show a marked increase in the fraction of delayed projects when scheduled.

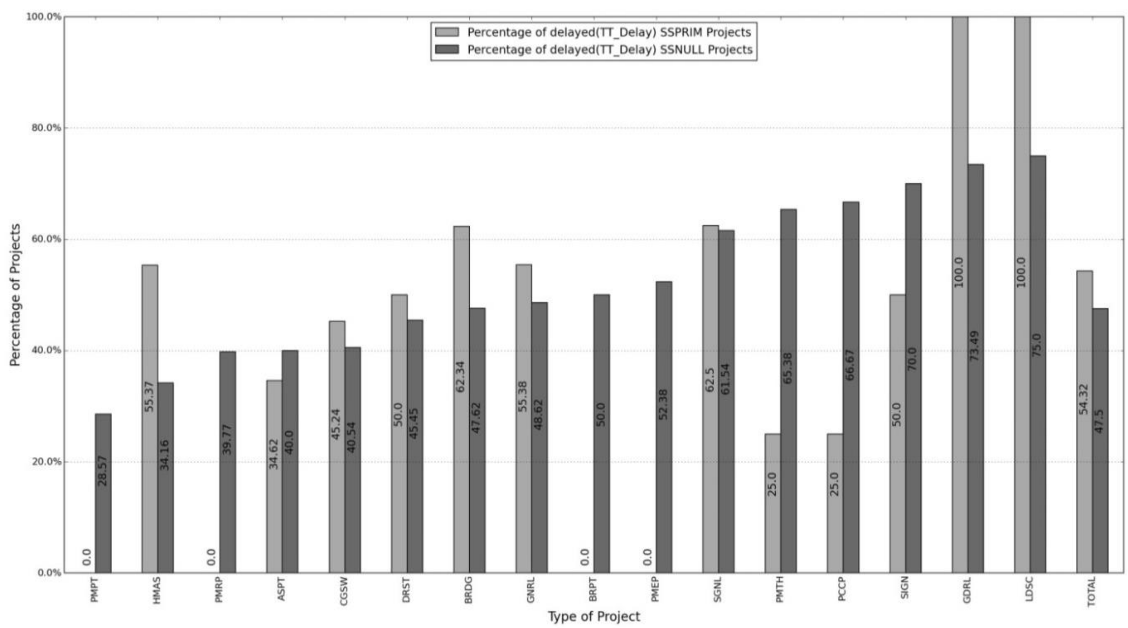

Figure 4.1 Comparison of delayed (TT_Delay) SSPRIM projects and delayed SSNULL projects (by project type).

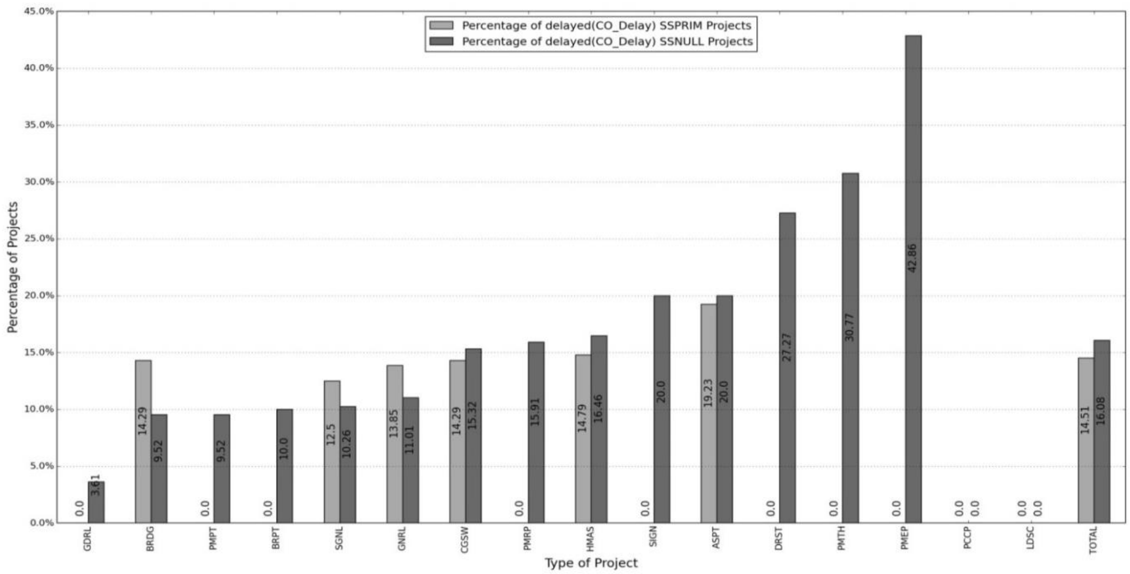

Figure 4.2 Comparison of delayed (CO_Delay) SSPRIM projects and

In comparing the results shown in Figure 4.1 and Figure 4.2, it can be seen that there is a reduction in the number of delayed projects when delay is measured using the adjusted completion date. Moreover, across all project types, the percent of change order adjusted delayed in scheduled projects is 14.51% compared to 16.08% in the unscheduled group. This is one of only a few scenarios where scheduling resulted in a reduction in the number of delayed projects.

Table 4.6 Impact of Using a Critical Path Method (CPM) Schedule on Project Delays by Project Size

Project size Groups	Total number of Projects	Total number of SSPRIM Projects	Number of Delayed Projects	
			Number of projects delayed after original completion date (nTT_Delay)	Number of projects delayed after adjusted completion date (nCO_Delay)
Small Projects	702	206	275	85
Medium Projects	670	382	338	104
Large Projects	725	570	462	130
Total	2,097	1,158	1,075	319

Table 4.6 shows the effectiveness of using CPM schedules on the delay of SCDOT projects in terms of project size. It also shows the number of SSPRIM projects in each group that were delayed in terms of original completion date (TT_Delay) and adjusted completion date (CO_Delay), respectively.

From Table 4.6, the large-sized projects have an increased fraction of projects with a schedule than the other two groups. Most of the projects in the large group are scheduled (78.62%). In each group, the number of projects that were delayed, measured by adjusted completion date (nCO_Delay) is lower than those measured by original completion date (nTT_Delay).

Table 4.7 Impact of Using a Critical Path Method (CPM) Schedule on Project Delays by Project Duration groups

Project duration Groups	Total number of Projects	Total number of SSPRIM Projects	Number of Delayed Projects	
			Number of projects delayed after original completion date (nTT_Delay)	Number of projects delayed after adjusted completion date (nCO_Delay)
Short Projects	364	158	175	66
Medium Projects	1,294	714	642	200
Long Projects	439	286	258	53
Total	2,097	1,158	1,075	319

From Table 4.7, In case of delay after original completion date (nTT_Delay), long project group has fewer fraction of projects (48.1%) that were delayed than the other two groups (short: 58.8% and medium: 49.6%). This same scenario of delay is also found in case of delay after adjusted completion date (nCO_Delay).

4.4 Identification of Factors Associated with Delay

The statistical significance between the number of projects that were scheduled and projects that were delayed is tested by Chi-Squared test for independence across all project types, SCDOT districts and project size. The original completion date (TT_Delay) and adjusted completion date (CO_Delay) are used to measure delay. The results of the Chi-Square test for numerous projects are presented in Table 4.8.

Only two combinations are found to be statistically significant at 0.05 level of significance and they are shown in bold face in Table 4.8. The results indicate that there is statistically significant evidence that the number of scheduled projects is not independent of the number of delayed projects when considering all projects and TT_Delay for determining delay.

The same association is found for scheduled HMAS projects for nTT_Delay. However, the two statistically significant values considering the TT_Delay mentioned above show a larger fraction of delayed projects in SSPRIM vs. SSNULL (all projects: 54.32% vs. 47.50% and for HMAS project: 55.35% vs. 34.02%).

Chi-Squared test results for SCDOT districts are also shown in Table 4.8. There are only two districts (i.e., District 1 and District 7) that show statistically significant difference in delay (TT_Delay) between SSPRIM and SSNULL projects. In these two districts, the SSPRIM projects show an increase in the fraction of delayed projects using nTT_Delay. However, District 5 shows statistically significant evidence that there is a difference in nCO_Delay between SSPRIM and SSNULL projects and a reduction of 7.58% in the fraction of delayed projects for SSPRIM (4.31% vs 11.89) projects.

Table 4.8 Chi-Squared Test Results for Project Types, SCDOT Districts and Project Size Groups

	Number of projects delayed after original completion date (nTT_Delay)			Number of projects delayed after adjusted completion date (nCO_Delay)		
	Delayed scheduled Projects (%)	Delayed unscheduled Projects (%)	*p*-value	Delayed scheduled Projects (%)	Delayed unscheduled Projects (%)	*p*-value
Chi-square test results for project types						
ALL	**54.32**	**47.50**	**0.002**	14.51	16.08	0.339
ASPT	34.62	40	0.7208	19.23	20	>0.999
BRDG	62.33	47.62	0.334	14.29	9.52	0.8357
CGSW	45.24	40.54	0.7323	14.28	15.32	>0.999
GNRL	55.38	48.62	0.3112	13.84	11	0.5957
HMAS	**55.35**	**34.02**	**0.000**	14.75	16.60	0.553
Chi-square test results for SCDOT districts						
1	**73.57**	**62.14**	**0.035**	20.21	15.71	0.367
2	57.47	49.55	0.233	14.37	15.04	>0.999
3	46.31	41.79	0.519	13.42	17.91	0.381
4	55.36	54.55	0.986	20.83	23.14	0.746
5	36.36	34.26	0.771	**4.31**	**11.89**	**0.014**
6	53.50	47.55	0.361	15.29	14.69	>0.999
7	**60.19**	**43.66**	**0.014**	14.81	14.79	>0.999
Chi-square test results for project size groups						
Small	35.92	40.52	0.293	8.74	13.51	0.102
Medium	48.43	53.13	0.260	15.18	15.97	0.864
Large	64.91	59.35	0.237	**16.14**	**24.52**	**0.022**
Chi-square test results for project duration groups						
Short	48.1	48.06	>0.999	**13.29**	**21.84**	**0.049**
Medium	**52.66**	**45.86**	**0.017**	14.85	16.21	0.551
Long	61.89	52.94	0.087	14.33	7.84	0.066

Chi-squared test results for different project size are also shown in Table 4.8. The test results show that for large projects, there is statistically significant evidence that the number of scheduled projects (SSPRIM) is not independent of the number of delayed projects when considering CO_delay. For large projects, there is a reduction of 8.38% in the fraction of delayed projects in SSPRIM vs. SSNULL (16.14% vs. 24.52%).

Table 4.9 t-test Results for Project Types (Considering Original and Adjusted Completion Date for Delay)

Project Type	Scheduled projects (SSPRIM)		Unscheduled projects (SSNULL)		Improvement for having a schedule (%)	t-value	Variance	p-value
	Mean delay (days)	S.D. (days)	Mean delay (days)	S.D. (days)				
t-test results for project type considering Delay (in days) after original completion date (TT_Delay)								
All	**121.47**	**143.59**	**95.61**	**106.93**	**-27.05**	**3.384**	**Not Equal**	**0.0007**
ASPT	81.5	105.88	94.4	89.03	13.66	-0.408	Equal	0.686
BRDG	**156.44**	**221.58**	**50.7**	**54.98**	**-208.56**	**2.905**	**Not Equal**	**0.005**
CGSW	66.16	69.08	75.98	79.17	12.92	-0.469	Equal	0.64
GNRL	**153.76**	**187.15**	**86.57**	**89.96**	**-77.62**	**3.076**	**Not Equal**	**0.002**
HMAS	**114.11**	**121.52**	**70.88**	**105.48**	**-60.99**	**3.025**	**Equal**	**0.003**
t-test results for project type considering delay (in days) after adjusted completion date (CO_Delay)								
All	32.20	50.13	38.85	52.31	17.11	-1.158	Equal	0.248
ASPT	46.5	56.12	44.5	52.13	-4.50	0.083	Equal	0.935
BRDG	27.55	23.72	7.5	3.54	-267.27	1.152	Equal	0.274
CGSW	18.5	29.51	32.41	48.13	42.92	-0.659	Equal	0.517
GNRL	47.15	91.13	29.92	30.81	-57.60	0.876	Not Equal	0.387
HMAS	28.81	37.05	34.23	42.01	15.81	-0.766	Equal	0.445

In the above, the number of delayed projects is discussed. In the following, the mean delay (in days) is analyzed. The null hypothesis (H_0) is that there is no statistical difference between the mean number of delay (in days) between SSPRIM and SSNULL projects. These tests are conducted for all projects by type, SCDOT district and project size.

The results of the t-test for different project types are shown in Table 4.9 considering both TT_Delay and CO_Delay, respectively. The results from Table 4.9 show that, for the TT_Delay, all, bridge, general, and hot-mixed asphalt paving have statistically significant increase in the mean delay for projects with a CPM schedule.

Table 4.10 t-test Results for SCDOT Districts (Considering Original and Adjusted Completion Date for Delay)

SCDOT District	Scheduled projects		Unscheduled projects		Improvement for having a schedule	t-value	Variance	p-value
	Mean Delay*	SD(days)	Mean Delay*	SD(days)				
t-test results for SCDOT districts considering delay (in days) after original completion date (TT_Delay)								
1	163.73	152.93	133.60	138.73	-22.55	1.50	Equal	0.135
2	96.14	156.54	77.86	82.31	-23.48	0.813	Not Equal	0.418
3	69.96	77.22	68.91	74.64	-1.52	0.076	Equal	0.939
4	101.68	113.68	87.21	94.68	-16.59	0.846	Equal	0.398
5	131.64	146.27	110.71	145.60	-18.91	0.782	Equal	0.435
6	*125.88*	*153.34*	*87.38*	*69.98*	*-44.06*	*1.914*	*Not Equal*	*0.057*
7	133.52	154.04	89.92	100.44	-48.49	1.87	Not Equal	0.062
t-test results for SCDOT districts considering delay (in days) after adjusted completion date (CO_Delay)								
1	43.90	60.73	29.25	27.91	-50.08	0.811	Not Equal	0.421
2	26.35	30.39	29.09	29.78	9.41	-0.258	Equal	0.798
3	24.28	38.55	28.38	25.07	14.44	-0.286	Equal	0.776
4	26.17	35.25	45.68	57.12	42.71	-1.664	Not Equal	0.101
5	44.18	65.98	51	53.68	13.38	-0.266	Equal	0.792
6	45.52	72.03	44.08	38.27	-3.24	0.065	Not Equal	0.948
7	15.35	15.88	43.35	82.88	64.59	-1.482	Not Equal	0.147

Table 4.11 t-test Results for Project Size Groups (Considering Original and Adjusted Completion Date for Delay)

Project Size Groups	Scheduled projects		Unscheduled projects		Improvements for having a schedule	t-value	Variance	p-value
	Mean Delay (days)	SD (days)	Mean Delay (days)	SD (days)				
t-test results for project size groups considering delay (in days) after original completion date (TT_Delay)								
Small	67.01	65.89	82.52	98.64	18.79	-1.50	Not Equal	0.136
Medium	88.57	106.63	99.12	89.58	10.64	-0.85	Equal	0.396
Large	*150.28*	*163.88*	*119.18*	*128.77*	*-26.09*	*1.956*	*Not Equal*	*0.052*
t-test results for project size groups considering delay (in days) after adjusted completion date (CO_Delay)								
Small	**16.61**	**11.75**	**36.12**	**54.73**	**54.01**	**-2.70**	**Not Equal**	**0.009**
Medium	28.31	35.64	40.26	54.84	29.68	-1.28	Not Equal	0.205
Large	37.71	60.84	41.95	45.42	10.11	-0.436	Not Equal	0.664

The results of t-test for all the SCDOT districts are also presented in for TT_Delay and CO_Delay respectively. The mean delay based on original completion date is less in unscheduled projects in all districts albeit the p-values are greater than 0.05. The delay including change orders by district is not statistically significant.

Table 4.11 shows the t-test results for the projects categorized by project size. There is an almost significant decrease in the mean delay from 150 to 119 days for unscheduled large projects (p-value = 0.052). Small-sized projects show an increase in the change order adjusted delay for unscheduled projects. This one category indicates CPM schedules mitigate project delays. Table 4.12 shows similar results for project duration groups.

Table 4.12 t-test Results for Project Duration Groups (Considering Original and Adjusted Completion Date for Delay)

Project Duration Groups	Scheduled projects		Unscheduled projects		Improvements for having a schedule	t-value	Variance	p-value
	Mean Delay (days)	SD (days)	Mean Delay (days)	SD (days)				
t-test results for project duration groups considering delay (in days) after original completion date (TT_Delay)								
Short	**100.05**	**103.31**	**56.58**	**77.85**		**2.621**	**Not Equal**	**0.009**
Medium	104.77	129.59	85.7	96.92		1.585	Not Equal	0.115
Long	**166.15**	**174.43**	**72.5**	**46.46**		**4.805**	**Not Equal**	**0.0**
t-test results for project size groups considering delay (in days) after adjusted completion date (CO_Delay)								
Short	27.33	20.68	43.77	67.18		-1.093	Not Equal	0.278
Medium	31.67	50.07	36.94	46.86		-0.765	Equal	0.445
Long	36.07	35.33	60.58	23.29		0.063	Not Equal	0.949

4.5 Survey Results of the Use Of CPM

The online questionnaire survey was distributed nationwide to all the DOTs, Resident construction Engineers and contractors working with DOTs. The survey was open for a period of little over 1 month, from June 14, 2017 to July 23, 2017. A total of 22 states with 23 people from the DOTs, 51 resident engineers form 16 different states and 45 contractors working in 16 different states responded to the survey. The survey centered on selection criteria for CPM projects, preferred scheduling techniques and software use, contract requirements of CPM projects, decision making on CPM schedules, delay factors associated with CPM, RCE evaluation of CPM use by the contractors, appointment and tasks of schedulers and value of CPM in the company. Section 5.6.1 to 5.6.3 presents the viewpoint of DOTs, RCEs and contractors on CPM.

4.5.1 State DOTs viewpoint on CPM scheduling

Question 2 in the DOT survey asked about the use of CPM method in DOT projects. It is found from the survey that; CPM schedule method is undoubtedly most widely used scheduling technique used by the state DOTs.

CPM schedule method is undoubtedly most widely used scheduling technique used by the state DOTs. From the survey of state DOTs, nearly 95% of the responding state DOTs (22 out of 23) use CPM for project management. The state DOTs not only use CPM but also use other scheduling techniques. shows that the eight (8) state DOTs (36.4%) only use CPM schedules for project management. Figure 4.3 Other techniques used by state DOTs for scheduling that includes Gantt charts (50%), milestone charts (13.6%) and other. The responding state DOTs mentioned in the comment section of the other techniques for scheduling which includes bar charts, customized scheduling forms, and monitoring charts. Among these other techniques, 50% of state DOTs (11 out of 22) that use CPM scheduling also use Gantt charts and it also stands out as a popular technique of scheduling.

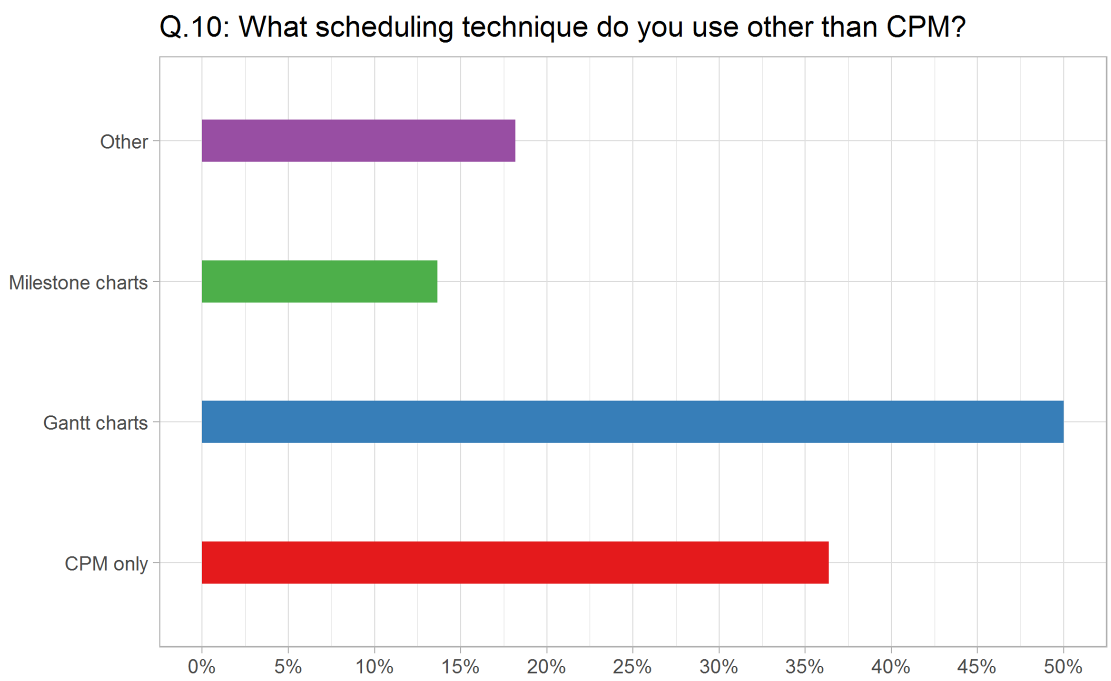

Figure 4.3 State DOTs answer to question 10

Question 3 explores the criteria for selecting a project for CPM scheduling. Figure 4.3 shows that the top three reasons for selecting a project for CPM schedules indicated by the state DOTs are: complexity of the project (16 out of 23, 69.6%), risk associated with the project (12 out of 23, 52.2%), total bid amount of the project (6 out of 23, 26.1%). Other reasons for the selection of CPM schedules include: following rules and regulation of the agency (21.7%), contract special provisions, incentives/disincentives, preference of contractors, and use CPM schedules for all projects.

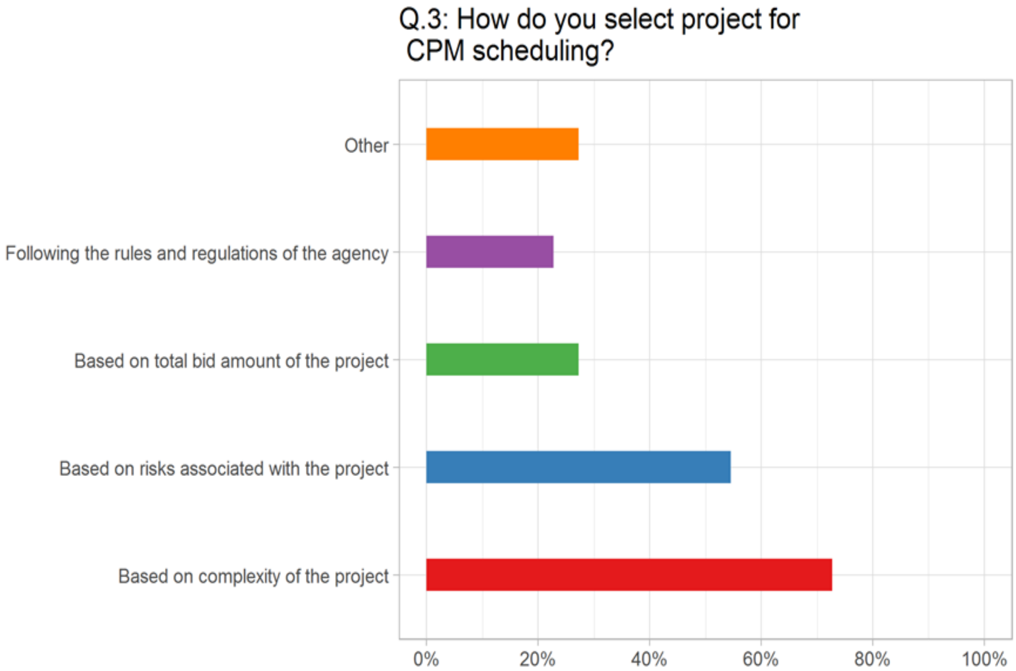

Figure 4.4 State DOTs answer to question 3

Questions 4 and 5 examined the contractual specifications of CPM for projects. Figure 4.5 reveals that the state DOTs (22) that use CPM schedules, only 13.6% state DOTs (3 out of 22) indicated that they do not require CPM specification for each of their projects. Among the state DOTs that require a CPM specification for each of their projects, the state DOTs were equally split (8 out of 22, 36.4%) as to whether all or some of the projects require CPM specifications. The remaining state DOTs (3 out of 22, 13.6%) require CPM specification for most of their projects. Figure 4.6 shows that half of the state DOTs (11 out of 22) reported that they use a standard CPM specifications for all the projects while nearly 18% (4 out of 22) of them use a customized CPM specifications for project management.

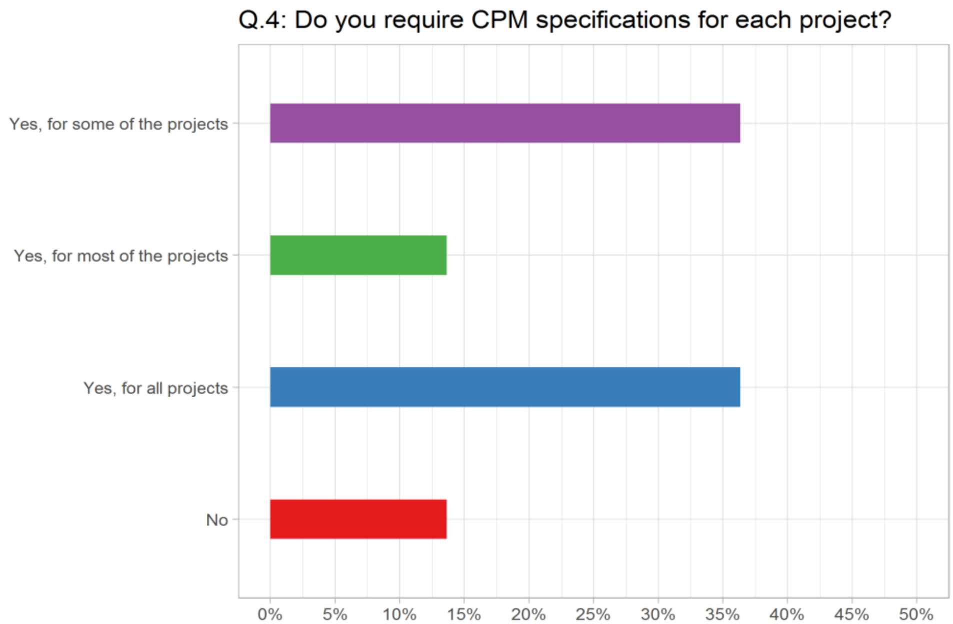

Figure 4.5 State DOTs responses to question 4

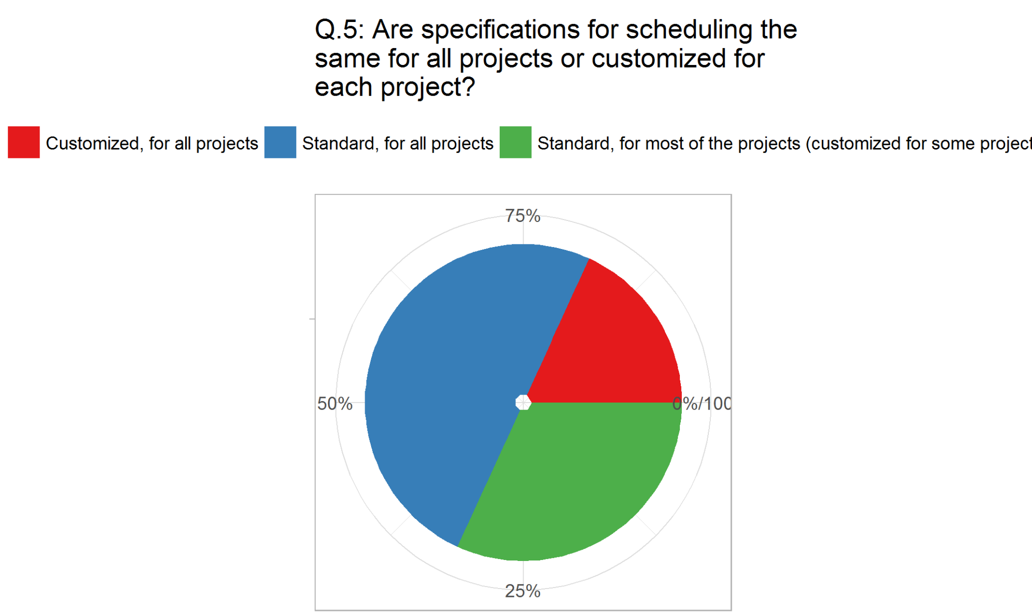

Figure 4.6 State DOTs responses to question 5

Questions 6, 11, 12, and 13 dealt with software preferences for scheduling for transportation projects. Different versions of Primavera P6 are the first choice for CPM scheduling. Figure 4.7 shows that all the responding state DOTs reported that they use different versions of Primavera P6 and half of the state DOTs (11 out of 22) use Primavera P6, version 8 for project management. Also, the use of other software for scheduling indicated by the state DOT includes: Primavera P3 (9.1%), different versions of MS Project (MS project 2010: 13%, MS project 2013: 4.3%, MS project 2016: 13%), and Asta PowerProject. In response to questions 11, 12, and 13 the respondents' software preference includes MS Excel, contractors' choice, pen/paper and customized DOT form (i.e. MDOT form 1130).

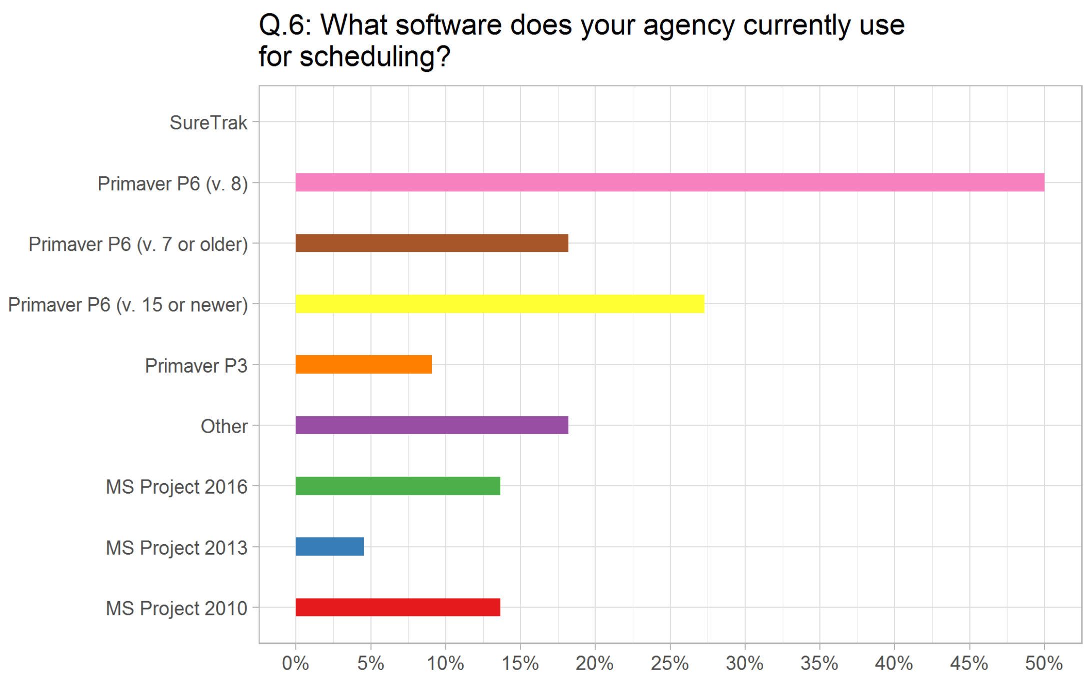

Figure 4.7 State DOTs responses to question 6

In response to question 7, as shown in Figure 4.8, reveals the type of information loaded with CPM schedules. Most DOTs incorporate either resource (5 out of 22, 22.7%) or cost (2 out of 22, 9%) or both (6 out of 22, 27.3%) in their CPM schedule. Other information in CPM schedules includes different specifications for cost and resource loading (i.e. cost and/or resource for if contract amount exceeds certain dollar values), and project specific calendars.

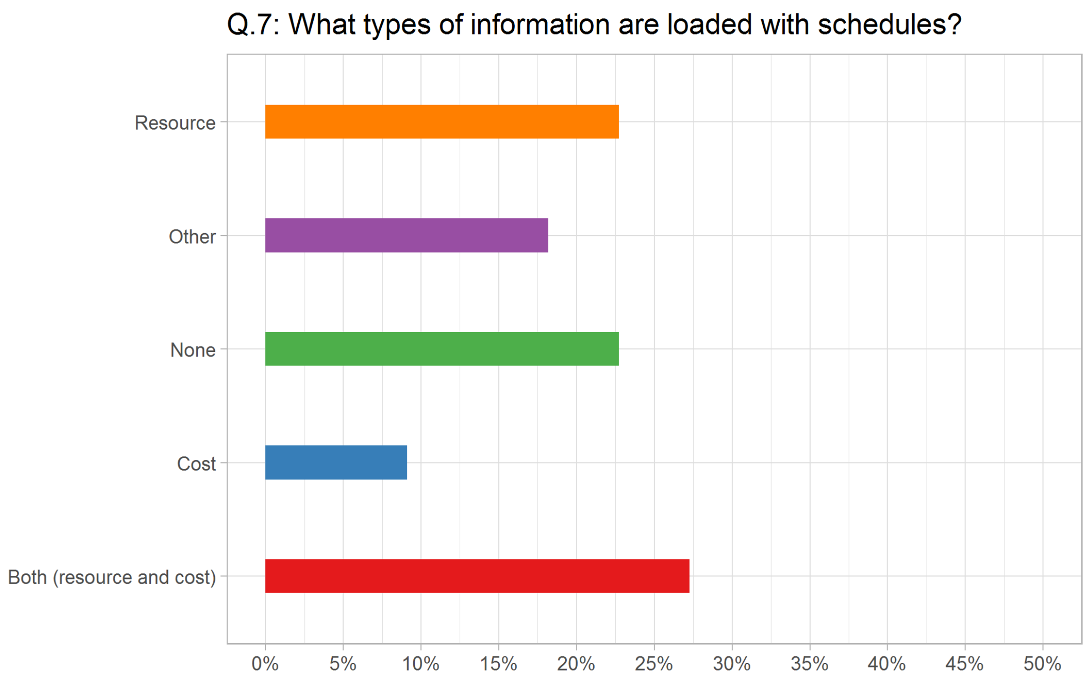

Figure 4.8 State DOTs responses to question 7

Question 8, 9, and 14 explores the option of cloud storage of schedule database and access to the database. Only three (3 out of 22) state DOTs are currently hosting their database on the cloud. Figure 4.9 shows that the state DOTs are indecisive about hosting its scheduling database on the cloud in the future. While nearly 10% (2 out of 22) have a certain plan to move its database to the cloud, 45% (10 of 22) of state DOTs indicated that they “may” move its scheduling database on to the cloud in the next five years. The remaining state DOTs (7 out of 22, 31.8%) have no plan to move its database on the cloud.

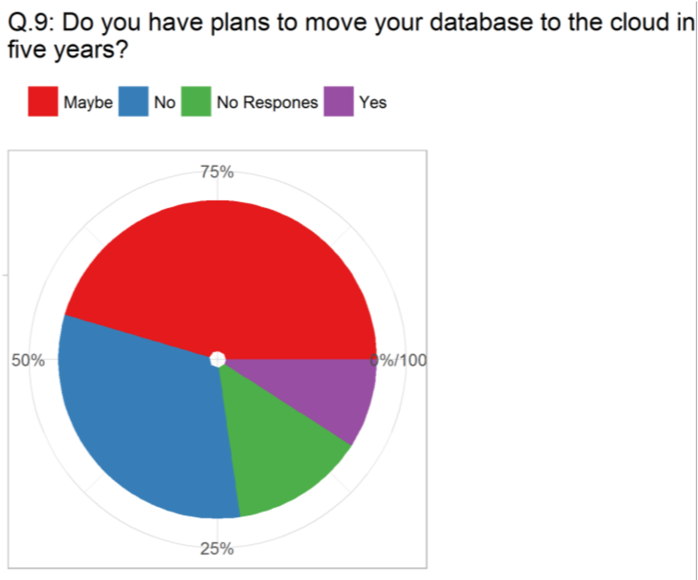

Figure 4.9 State DOTs response to question 9

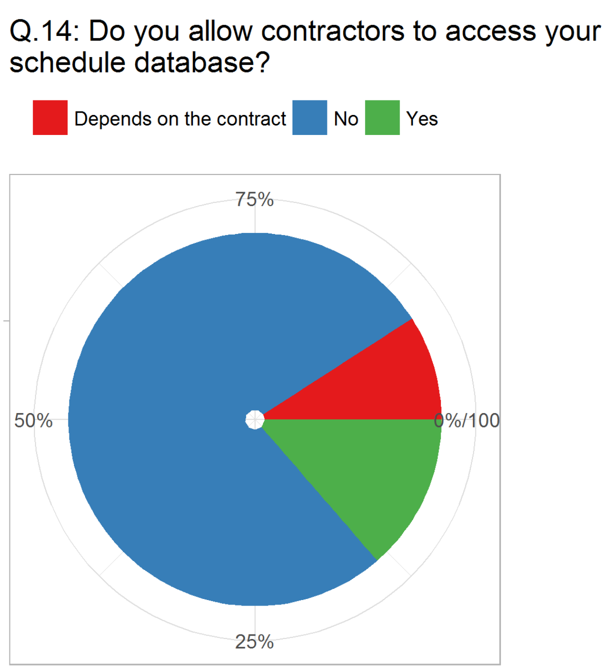

Figure 4.10 State DOTs responses to question 14

Figure 4.10 reveals that the state DOTs are very restrictive in terms of allowing contractors to access its schedules. More than two-thirds (17 out of 22, 77.3%) of the state DOTs do not allow contractors to access their schedules. Only few (2 out of 22, 9.1%) provide access to its scheduling provided it is recorded in the contract and the remaining respondent DOTs (3 out of 22, 13.6%) provide access to the schedules database.

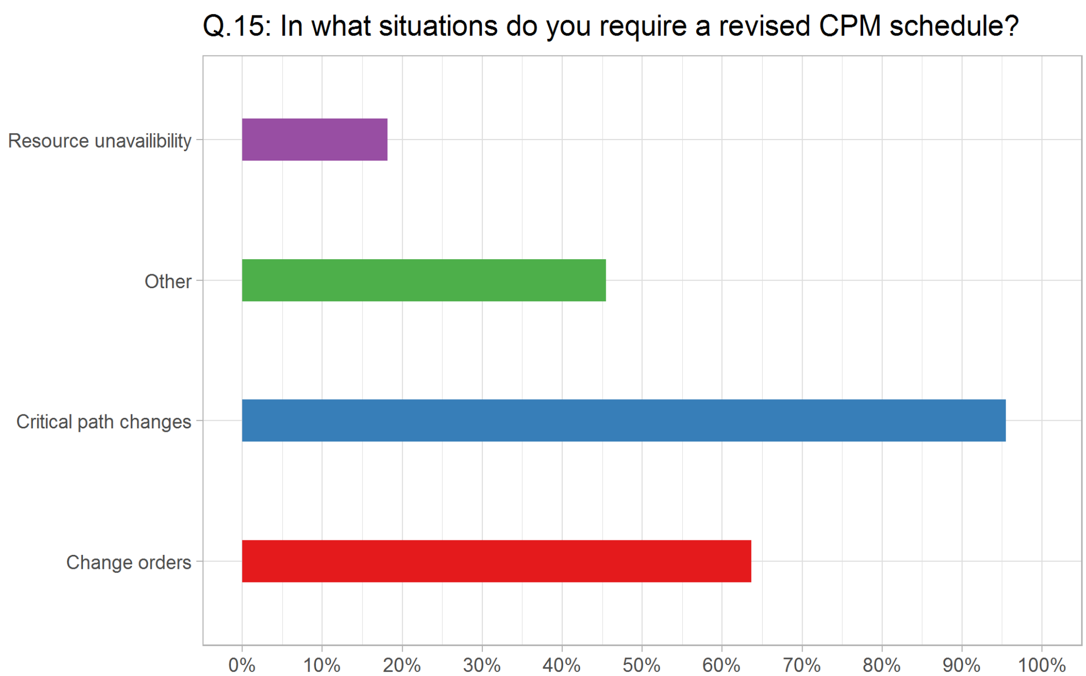

Figure 4.11 State DOTs responses to question 15

Questions 15 aims to find the reasons for a revised CPM schedule. Figure 4.11 shows that almost all of the state DOTs (21 out of 22, 95.5%) agreed that a revised CPM schedules is required if changes occur in the critical path of the project. Nearly 65% (14 out of 22) of the responding state DOTs indicated that change orders in a project was another reason for a revised CPM schedules. Other situations for a revised CPM schedules include: resource un-availability, changes of activity original duration, monthly updates, contract time changes, contractors' deviation from current progress schedules, project behind schedules exceeds certain days, and time extension for revised schedules.

It is unanimously agreed by all the state DOTs from responses on question 16 that they use CPM schedules as a forensic tool. All the state DOTs (22 out of 22) reported that, they rely on the CPM schedules for assessing claims. Among these state DOTs, little over 40% (9 out of 22) use CPM for all the claims for the project and the remaining state DOTs (13 out of 22) use it for assessing selected claims.

4.5.2 Resident construction engineers' viewpoint on CPM scheduling

A total of 51 resident construction engineers from sixteen (16) different states responded to the online questionnaire survey. Most of the participants of the survey (33 out of 51, 64.7%) are working for South Carolina Department of Transportation (SCDOT).

Resident construction engineers were asked in the question 2 of the survey for the criteria of selecting a project for CPM schedules. Figure 4.12 shows than, the top three reasons indicated were: complexity of the project (92.2%), risk associated with the project (60.8%), total duration of the projects (52.9%). Other reasons for selection of CPM schedules include: total bid amount of the project, previous experience with similar type of work or contractor, following rules and regulations of the agency/client. In addition to these some RCEs also mentioned anticipated conflicts, time incentives, and use CPM schedules for all projects as criteria for selecting projects.

There were couple of survey questions for the resident engineers regarding contractors' use of CPM schedules for projects. Nearly 30% of the resident construction

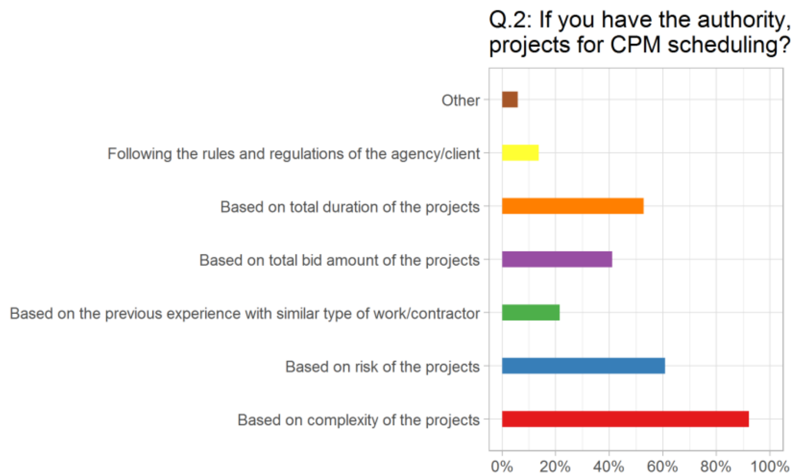

Figure 4.12 RCEs responses to question 2

Question 3 examined the decision-making aspect of CPM schedules by the RCEs. More than 80% (44 out of 51) of the responding resident engineers indicated that they rely on CPM for making decision on projects. Figure 4.13 presents that among them (34 out of 51, 66.7%) occasionally refer to CPM schedules for decision making. Close to 20% of responding RCEs (10 out of 51) refers CPM frequently while remaining 13.7% (7 out of 51) never use CPM schedules for decision making on the project.

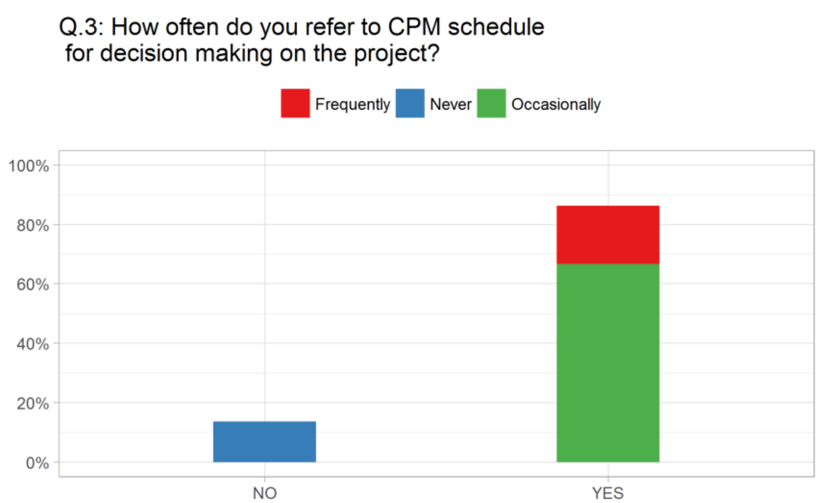

Figure 4.13 RCEs responses to question 3

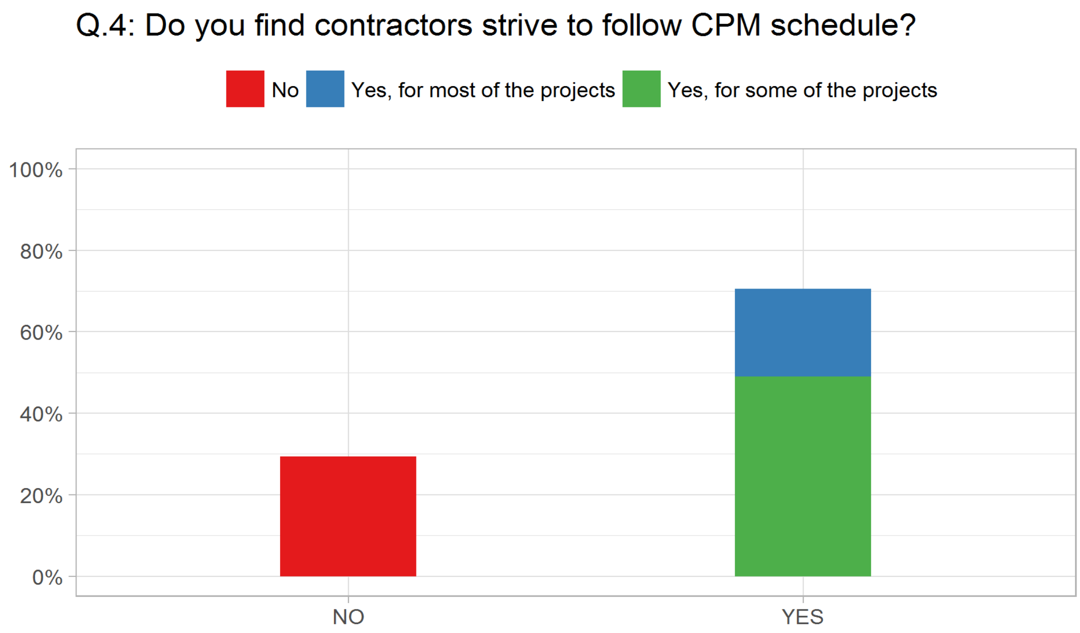

Figure 4.14 RCEs response to question 4

Questions 4 and 5 aimed at evaluating contractors' effort to use regarding CPM schedule by RCEs. Figure 4.14 shows that almost 70% of the responding RCEs (36 out of 51) replied that contractors strive to follow CPM schedules. Among the respondents who believe contractors make considerable effort to follow the CPM schedules indicated that nearly 69% (25 out of 36) do it for most of the projects. There were no resident engineers who mentioned that contractors strive to follow CPM schedules for all the projects. Responses of question 5 is shown in Figure 4.15. It reveals that over half of the responding resident engineers (28 out of 51, 54.9%) indicated that contractors prepare a CPM schedules whether it is required by the contract or not.

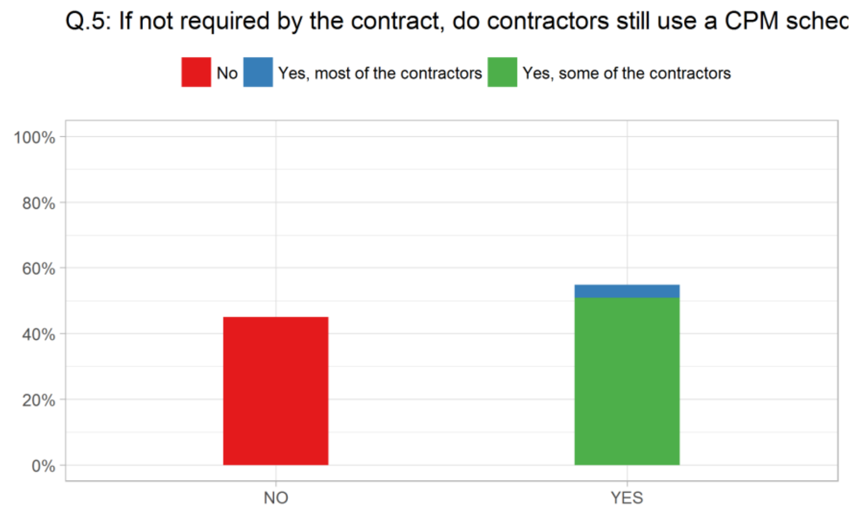

Figure 4.15 RCEs responses to question 5

Questions 6 through 9 are aimed to find the factors perceived by the resident engineers that results in extension of project planned duration. Figure 4.16 shows that a little over 55% of the resident engineers (29 out of 51) experience that the duration between the NTP and start of work of the construction projects consume a significant fraction of the total duration of the project. Among them, two-thirds (22 out of 29) of the resident engineers indicated that it occurs for some of the projects but not for all projects.

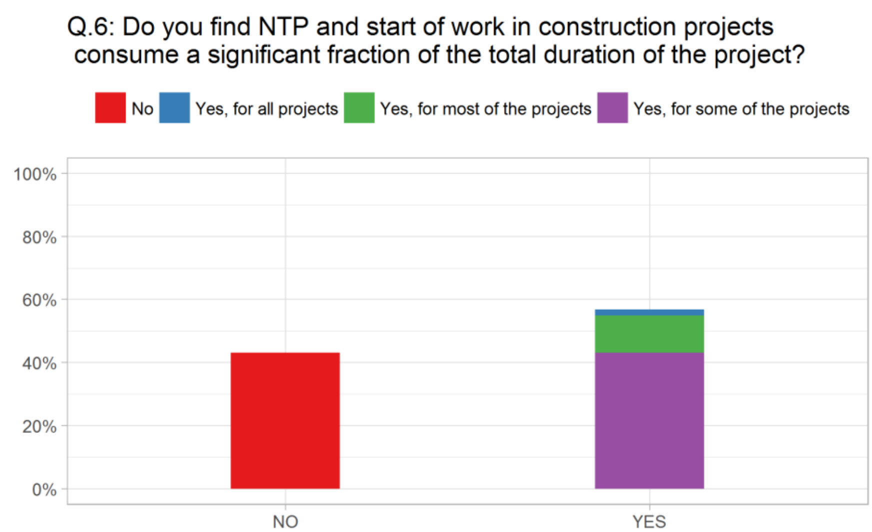

Figure 4.16 RCEs responses to question 6

In response to question 7, as shown in Figure 4.17, nearly 68% (35 out of 51) of the resident engineer observed that significant number of change orders from contractors occurs in the last third of the project. Among these resident engineers, 71% (25 out of 35) indicated that it occurs for some of projects but not for all projects.

Question 8 tries to find out the common reasons for project time extension. Figure 4.18 indicates the top reasons for requesting project extension indicated by the resident engineers are: contract modifications (70.6%), weather (66.7%), and change orders by owner (56.9%). Other reasons for project extension includes: inadequate planning and

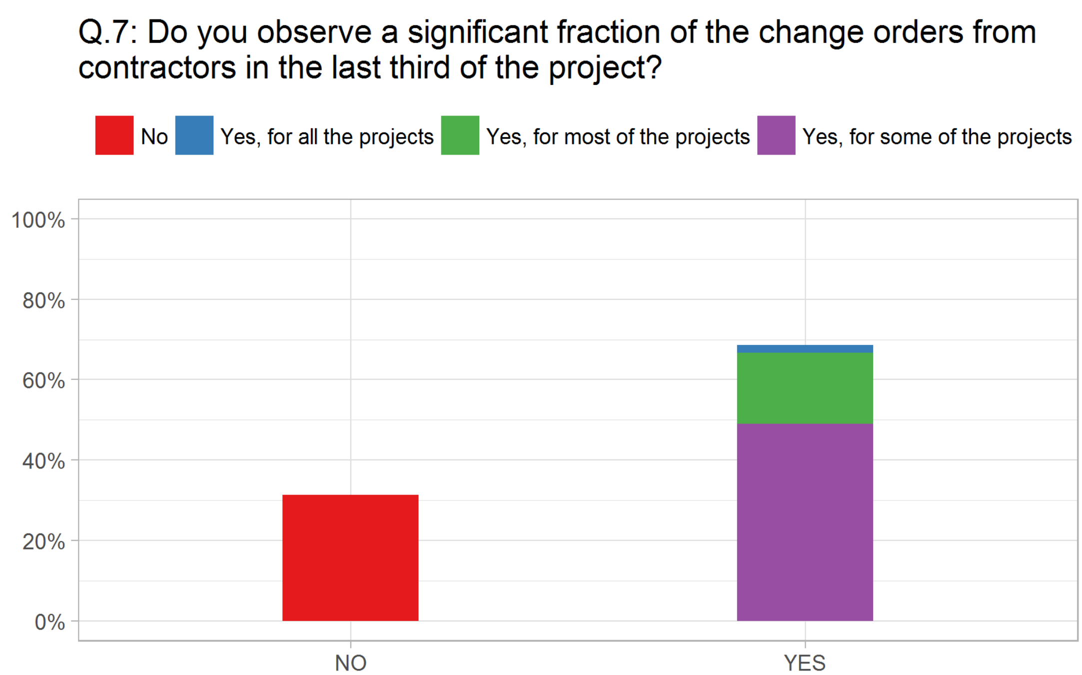

Figure 4.17 RCEs responses to question 7

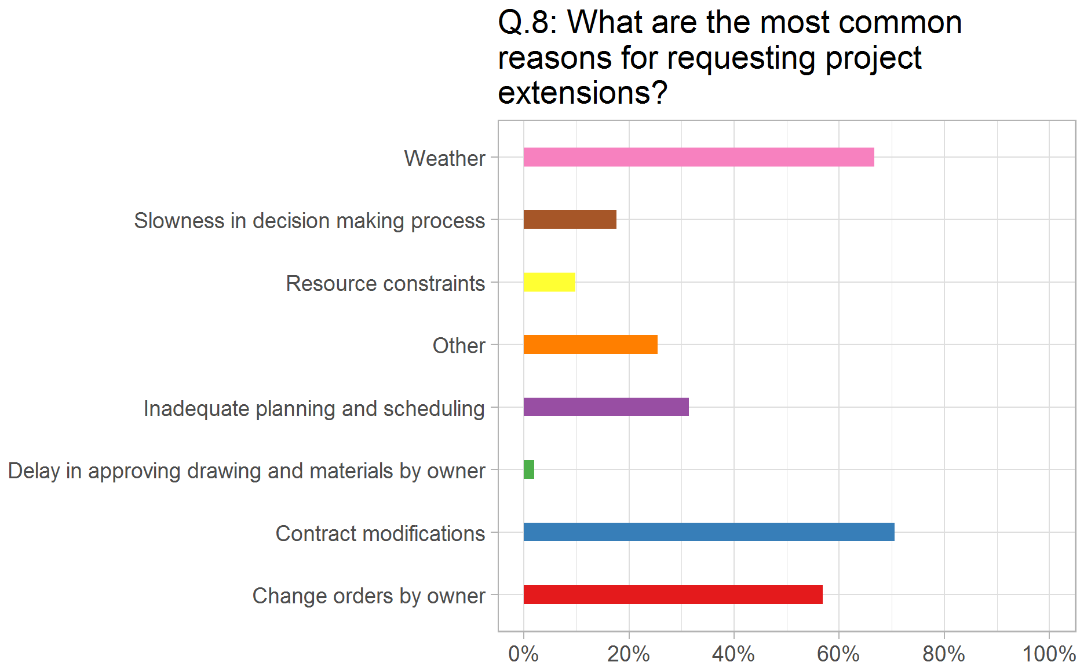

Figure 4.18 RCEs responses to questions 8

scheduling, resource constraints, delay in approving drawing and materials by owner. The main comment for this question from the resident engineers was that utility issues (i.e. conflicts, relocations, permissions, delays) play significant part for project time extension. Answer from resident engineer for Question 9 indicates that nearly 60% (31 out of 51) of the resident engineers indicated the CPM schedules do not reduce the number of change orders.

Answer to the Question 10 of the survey reveals that it is a widespread practice to use CPM for claim analysis and decision making for projects. Figure 4.19 shows that more than 80% (41 out of 51) of the resident engineers use CPM for assessing claims to some extent. Among them, 39% (16 out of 41) use CPM for all the claims related to projects.

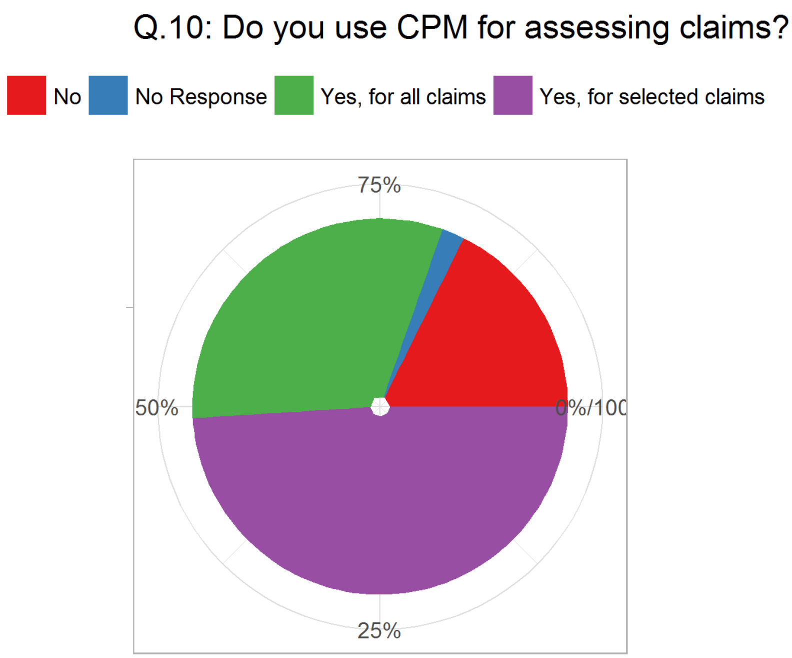

Figure 4.19 RCEs response to question 10

4.5.3 Contractors viewpoint on CPM scheduling

A total of 45 contractors working in sixteen (16) different states responded to the survey. Some of the contractors are working for multiple states and a few are working across all states. The top two responses are from the contractors working in the state of Michigan (17 out of 45, 37.8%) and South Carolina (12 out of 45, 26.7%).

Question 2 examined the contractual specification that requires a CPM schedule for the project. Figure 4.20 shows that more than 90% (41 out of 45) of the responding contractors replied that the projects require a CPM schedule. Majority of the contractors (17 out of 45, 37.8%) indicated that CPM schedule is required for most of the projects and close to 30% (13 out of 45, 28.9%) of contractors replied that it is a common requirement when the project contract amount is greater than 5 million.

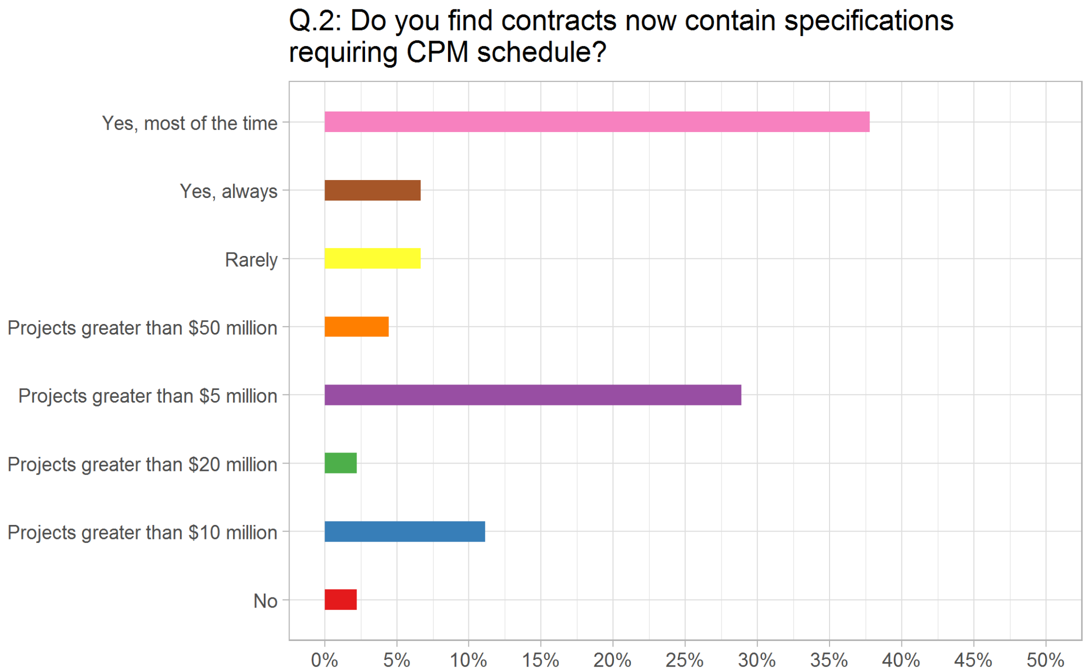

Figure 4.20 Contractors responses to question 2

Questions 3 and 7 aimed to find if the contractors maintained a separate schedule for projects. Figure 4.21 shows that two-thirds (30 out of 45) of the responding contractors prepare a CPM schedule whether it is required in the contract or not. In addition to that, answer to question 7 shown in Figure 4.22 reveals that three-fourth (34 out of 45) of the contractors maintain a separate schedule for work apart from the contract specified schedule. One-fourth (11 out of 45) of the responding contractors maintain a separate schedule for all their projects. It shows that having a CPM schedules for projects is important to the contractors.

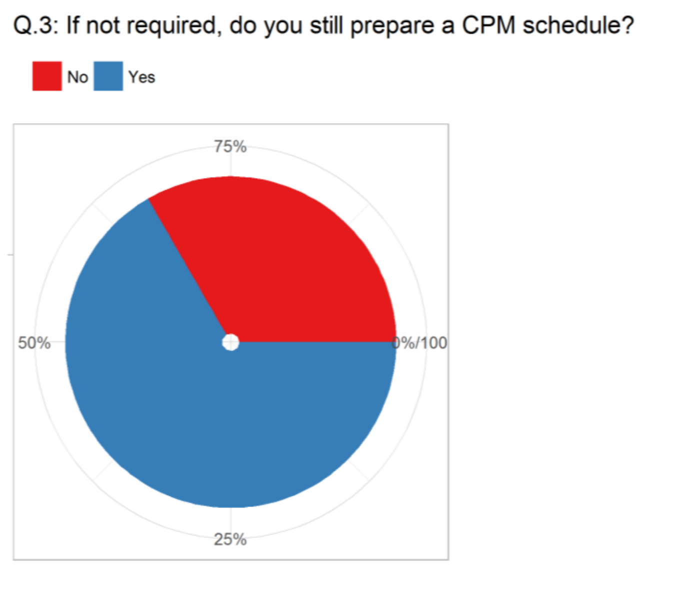

Figure 4.21 Contractors responses to question 3

The result of question 4, shown in Figure 4.23, revealed that more than 80% (37 out of 45) of the responding contractors use CPM for making decision on projects. In addition to that, contractors who use CPM schedule for decision making, more than half of them (20 out of 37) use it frequently.

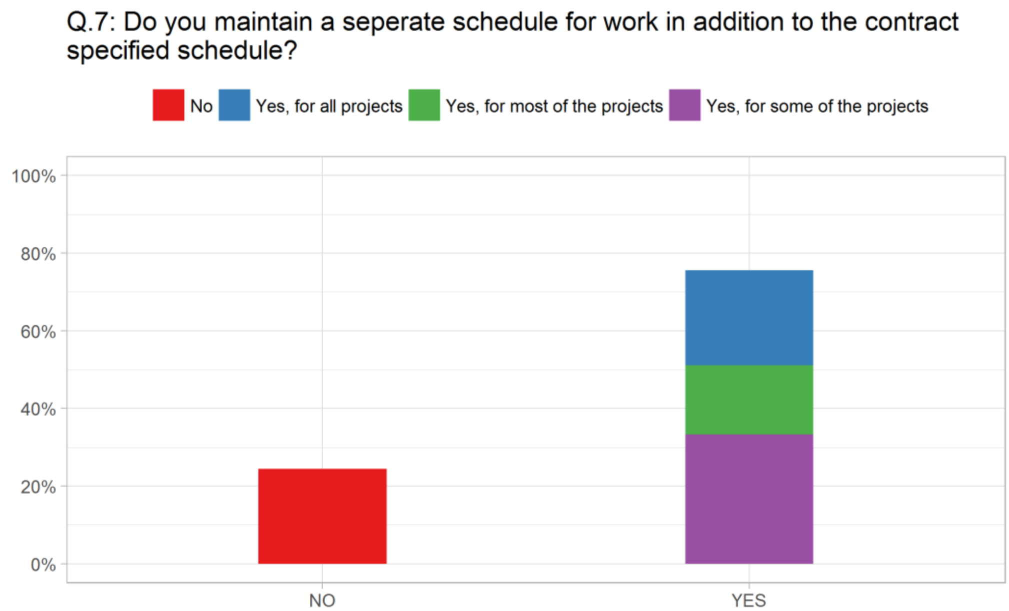

Figure 4.22 Contractors responses to question 7

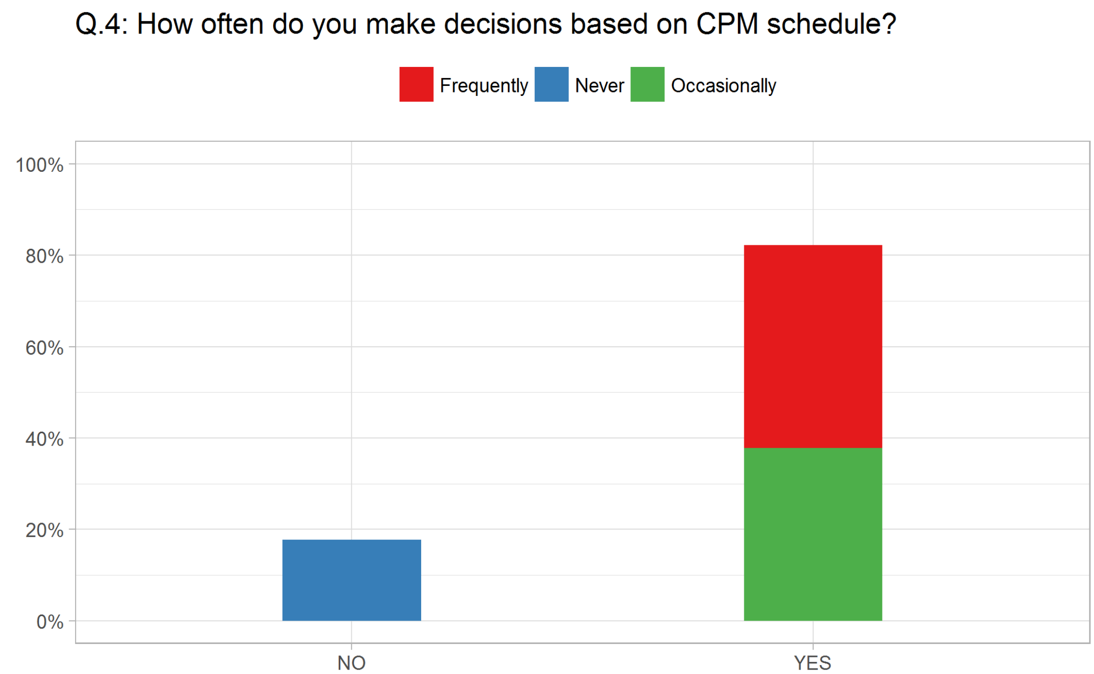

Figure 4.23 Contractors responses to question 4

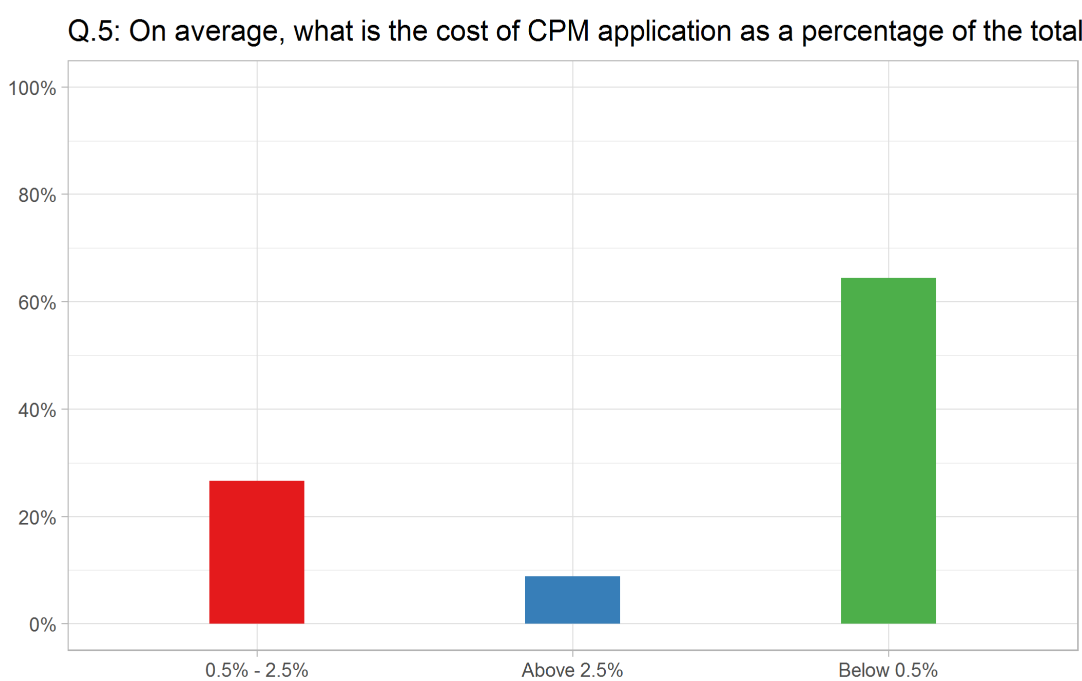

Figure 4.24 Contractors response to question 5

Question 5 discovers the cost of CPM schedule with respect to total cost of project. Figure 4.24 reveals that nearly 64% (29 out of 45) of the contractors indicated that the cost of applying CPM schedules in projects is below 0.5% of the total cost.

Question 6 explores the schedule technique used by the contractors. Figure 4.25 shows that nearly 30% (13 out of 45) of the responding contractors indicate that they only use CPM for scheduling. The use of only CPM schedules may be because of contract requirement from the owner**.** Gantt (26 out of 45, 57.8%) and Milestone charts (22 out of 45, 48.9%) are probably preferred techniques used by the contractors than only using CPM for scheduling. Apart from these three techniques for scheduling other techniques include bar charts, line chart, and two or 3 weeks look ahead schedules.

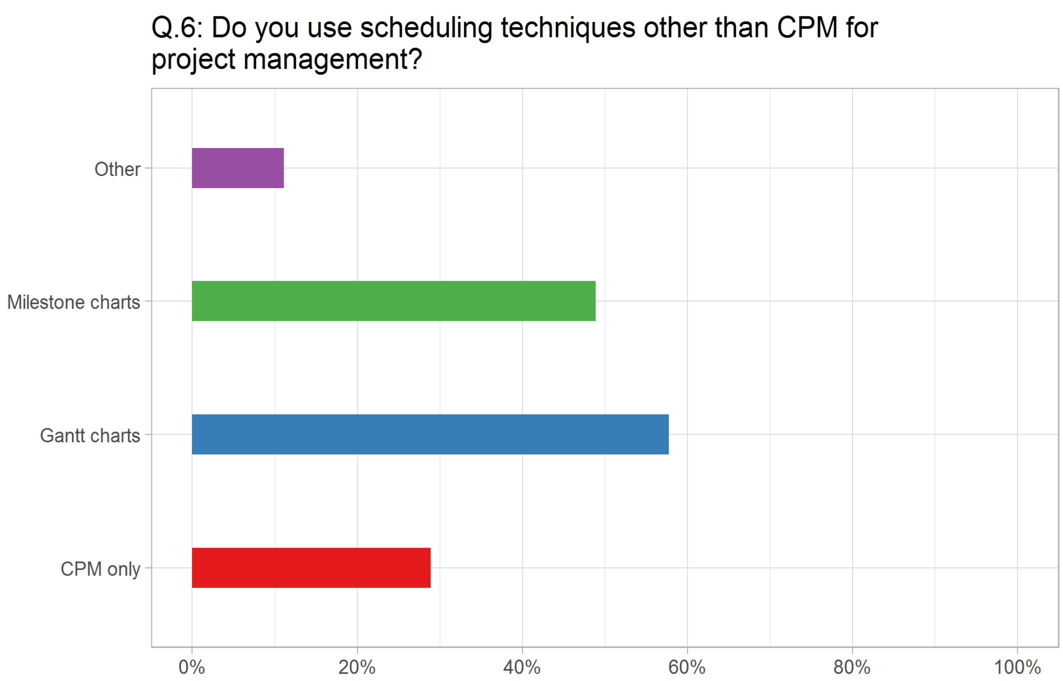

Figure 4.25 Contractors responses to question 6

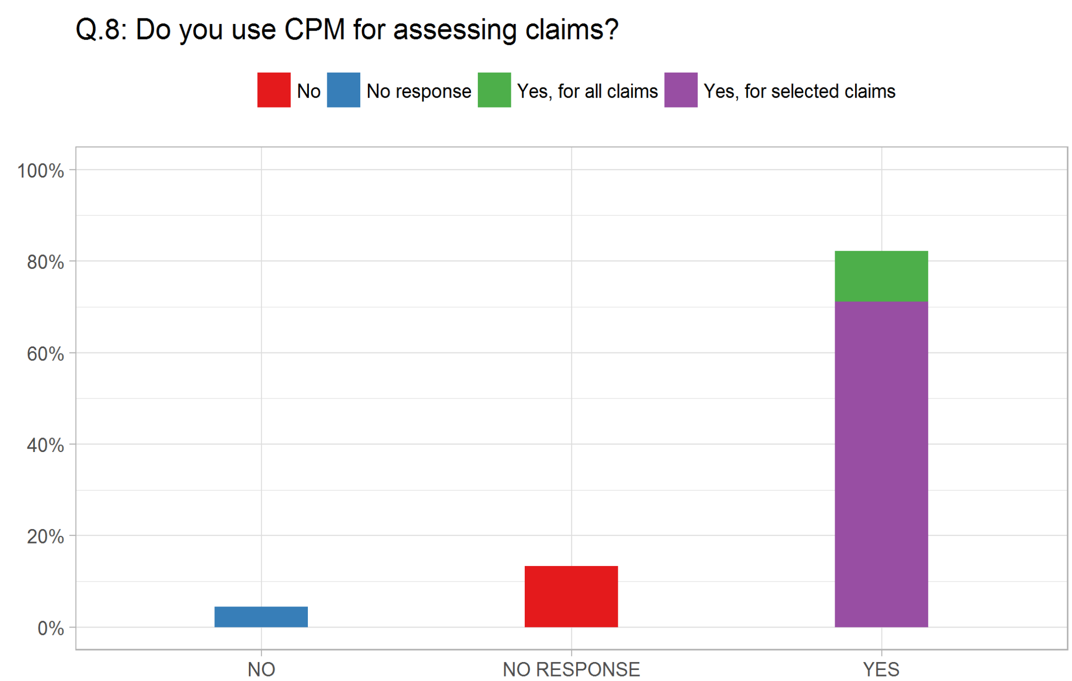

Figure 4.26 Contractors responses to question 8

Question 8 was about the use of CPM schedule as forensic tool. Figure 4.26 shows that more than 80% (37 out of 45) of the contractors use CPM for assessing claims to some extent. Among them 11.1% (11 out of 45) use CPM for all the claims related to projects.

Questions 9 to 11 aimed to find out the importance of a scheduler and tasks of scheduler. Figure 4.27 shows that more than half of the contractors (25 out of 45) only use their in-house personnel to perform the task of CPM scheduling. Contractors rarely (2 out of 45, 4.4%) use only outside consultant to perform CPM scheduling, but 40% (18 out of 45) of the contractors reported that they use a combination of in-house and outside consultant to prepare CPM schedules.

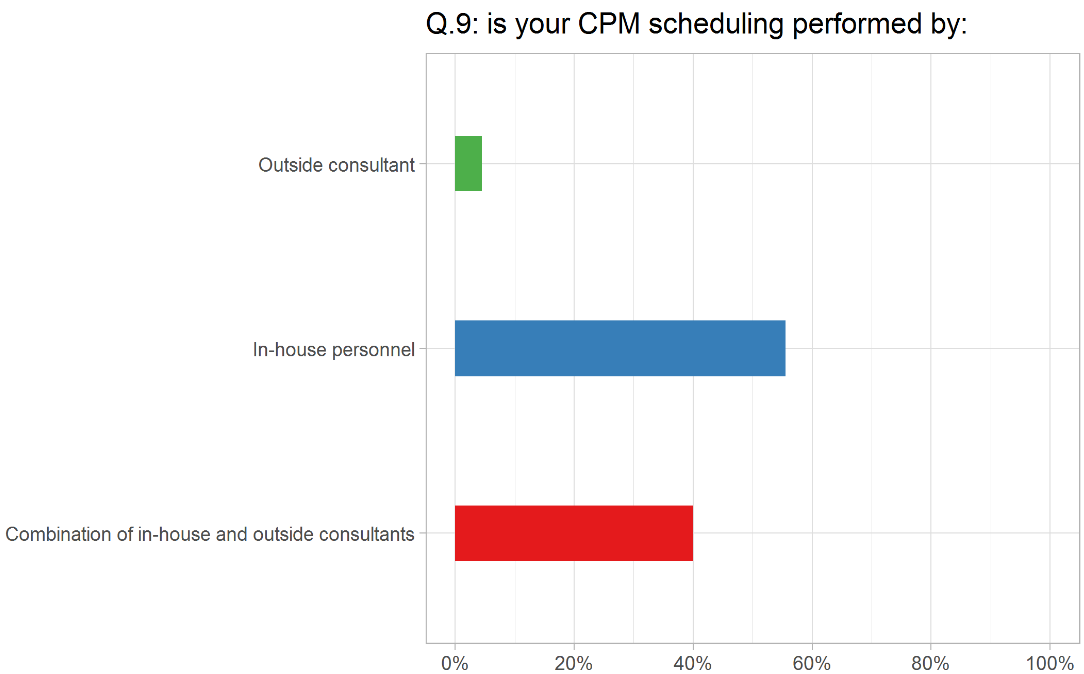

Figure 4.27 Contractors responses to question 9

Answer to question 10, as shown in Figure 4.28, shows that only close to 30% (13 out of 45) of the contractors indicated that they employ a dedicated person responsible for planning and scheduling tasks.

Question 11 explores the tasks of scheduler. Contractors responses, as shown in Figure 4.29 reveals that the in-house individuals not only prepare CPM schedules (6 out of 45) but also performs other duties such as, cost estimation (24 out of 45), project management other than scheduling (32 out of 45), and administration (12 out of 45). Comments made by the contractors to this question indicated some other duties the scheduler performed that includes: supervision, engineering, surveying, IT, labor, and organizing training program.

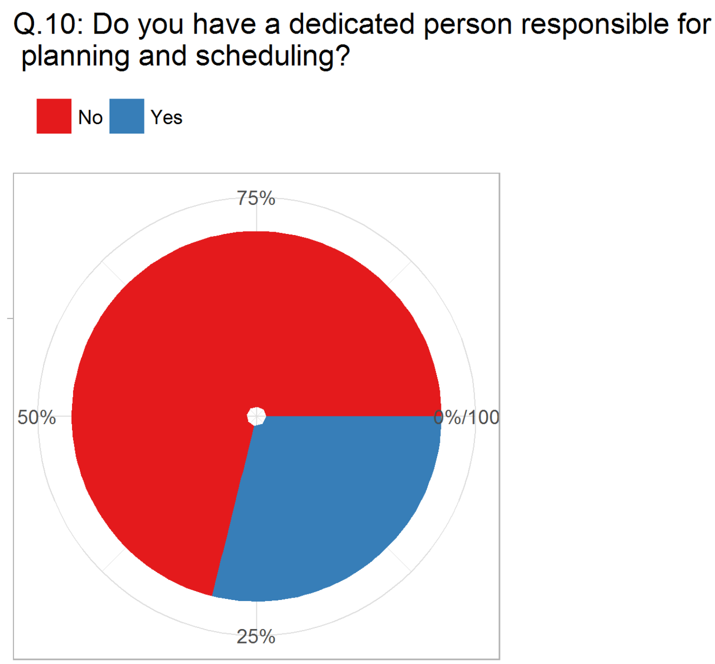

Figure 4.28 Contractors responses to questions 10

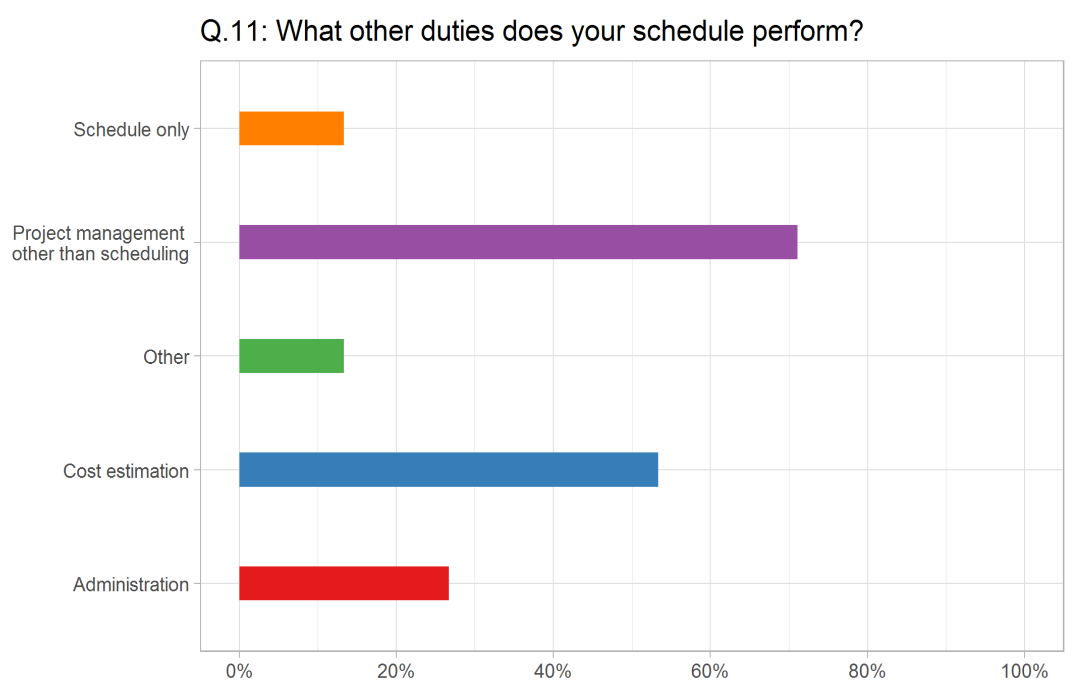

Figure 4.29 Contractors responses to question 11

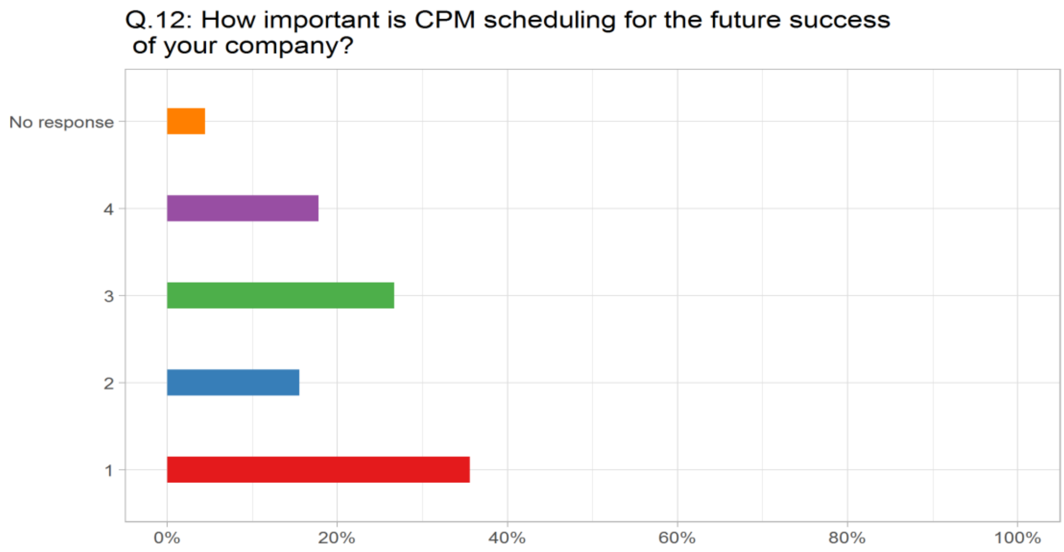

Figure 4.30 Contractors responses to question 12

Question 12 evaluates the importance of CPM schedule for the success of their company. On a scale of 4 (1 being very important and 4 being unsure) as shown in Figure 4.30, contractors ranked the importance of CPM. Less than one-fifth (8 out of 45) contractors have doubts regarding the contribution of using CPM schedules on their projects for future success. This is contrary to the belief that using CPM schedules for projects enhances the chance of a project to be successful.

4.6 Chapter summary

This chapter discusses findings into two parts. First part explores the statistical analysis of the transportation data and the later part shows the information acquired from the survey of DOTs, RCEs and contractors. Chi-square test of independence showed that scheduled project has association for certain project types, size and duration groups. Similar type of results is also found when comparing the mean delay for scheduled and unscheduled projects using t-tests. The survey reveals the viewpoint on CPM from DOTs, RCEs and contractors' perspective.

CHAPTER 5: DISCUSSION

5.1 Introduction

This chapter provided insights of the results from statistical analysis of the project data presented in chapter 4. The chapter discusses the results in two parts. First part focuses on the results obtained from the statistical analysis of the project data. The second part concentrates on the result from the online questionnaire survey.

5.2 Observations from the Statistical Analysis

Descriptive statistical analyses are shown in Table 4.1 to Table 4.4. Descriptive statistical analysis aims to find out the distribution of total number of projects in SiteManager and total number of project with a valid CPM schedules in Primavera database. The distribution of projects is explored in terms of independent variables, such as project types, project locations, project size groups, and project duration groups.

The SiteManager database contains a total of 2,097 projects for the analysis period (2007 - 2015). Most of the project are Hot-mixed Asphalt paving (HMAS: 48%). More than half of the total projects have a valid CPM schedules. Table 4.1 shows that certain types of projects are likely to have a CPM projects (i.e. ASPT, BRDG, GNRL, HMAS) than other types of project (i.e. paint and marking; sign and signal). The distribution of projects across the SCDOT districts is reasonably uniform. The total number of projects range from 250 to 352 with an average of 299 projects. All the SCDOT districts used CPM schedules for more than half of its projects except for District 7 (43.2%). District 2 used CPM schedules for majority of the projects (60.6%) comparing with other SCDOT districts. Distribution of projects by project size in Table 4.3 reveals that CPM schedules are more frequent in projects with larger bid amount than other groups. The same distribution is also found in case of project duration groups. Projects with longer duration tend to have a CPM schedule than others. CPM schedules helps in planning and managing projects. Since, larger and longer projects have more risks involved, they are inclined to CPM schedules. It can be concluded that, larger bid amount and longer projects of certain types of transportation projects are more likely to have a CPM schedules.

Table 4.5 to Table 4.7 and Figure 4.1 to Figure 4.2 explores the relationship between project delay and the use of CPM schedules in transportation projects. Project delay is measure in terms of original completion date and adjusted completion date. More than half of the projects that were delayed have a CPM schedules. Having a schedule was found to be not effective when considering the original completion date for delay. Besides, numerous project types (i.e. HMAS, GNRL) have shown an increase in fraction of delayed projects when scheduled. On the other hand, considering the adjusted completion date for delay shows that a CPM schedule was effective in reducing the fraction of delayed projects. This results also reciprocate for particular types of projects (i.e. ASPT, CGSW, HMAS) but not for all types. Across all project size groups, more projects were delayed considering original completion date than adjusted completion date. Similar results are also found when projects are categorized by project duration. These results show that for certain types of projects with any project size and duration, fewer scheduled projects have delay after considering the impact of change order.

A summary of the results from both chi-square test of independence and t-tests are shown in Table 5.1.

Table 5.1 Summary of the statistical tests

Independent variable	Chi-square test of Independence		t-tests	
	TT_Delay	CO_Delay	TT_Delay	CO_Delay
Project type				
ALL	Significant (-)	-	Significant (-)	-
ASPT	-	-	-	-
BRDG	-	-	Significant (-)	-
CGSW	-	-	-	-
GNRL	-	-	Significant (-)	-
HMAS	Significant (-)	-	Significant (-)	-
Districts				
1	Significant (-)	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	Significant **(+)**	-	-
6	-	-	-	-
7	Significant (-)	-	-	-
Project size				
Small	-	-	-	Significant **(+)**
Medium	-	-	-	-
Large	-	Significant **(+)**	-	-
Project Duration				
Short	-	Significant **(+)**	Significant (-)	-
Medium	Significant (-)	-	-	-
Long	-	-	Significant (-)	-

"-"is used if the result is not statistically significant for significance level of 0.05
(+) indicates that, improvement (reduced delay) for having a schedule.

The chi-square test of independence is used to answer the following question: *is there a statistically significant association between the number scheduled projects and number of delayed projects?* Considering original completion date for delay, the chi-square test of independence shows that number of scheduled projects of certain project types (i.e. ALL, HMAS), particular SCDOT districts (i.e. District 1 & 7) and medium duration projects are not independent of the number of delayed projects. However, all these statistically significant values show a larger fraction of delayed projects are scheduled projects. On the other hand, when considering adjusted completion date for delay, the number of scheduled projects for projects in particular districts (District 5), large-sized, and short duration are not independent of the number of delayed projects. The results indicate that fewer fraction of scheduled projects are delayed after taking into account of the impact of change order.

The t-tests tries to find the answer to the following question: *is there a statistically significant difference in mean delay days between scheduled projects and unscheduled projects?* Considering original completion date for delay, the t-test shows statistically significant results for certain project types (i.e. ALL, HMAS), short, and long duration projects. However, the mean delay of scheduled projects for these categories are larger than the unscheduled projects. When delay is measured using adjusted completion date, only small-sized projects are found to be significant. The mean delay for scheduled small-sized projects are smaller than the unscheduled projects.

5.3 Observations from the Survey Result

The purpose of the survey was to explore the viewpoint of DOT personnel, resident construction engineers and contractors on the impact and use of CPM schedules for transportation projects. The survey also tried to identify issues regarding specifications of CPM schedules for projects. The survey focused on the topics indicated in

Table 3.1. Twenty-three (23) DOT personnel, fifty-one (51) RECs and forty-five (45) contractors responded to three separate the surveys. The survey questions are attached

in Appendix-C and the summary of the surveys is presented in the Table 5.2. Some of the issues faced by DOTs, RCEs and contractors are:

- Gantt and Milestone charts method of scheduling are more popular than CPM among contractors. It is due to fact that these methods are easier to implement and do not require skilled personnel.
- Selection of CPM for projects depend mainly upon perceived risks and complexity of projects. The risks and complexities are measured in terms of size and duration of the project. More sophisticated risk analysis is required.
- Specifications of scheduling is common in transportation contracts. But most of the state agencies do not request resource/cost loading to enforce the use of CPM schedules.
- Contractors sometimes maintain separate schedule for work. As a result, the state agencies do not get a chance to review the actually implemented schedules on work. This reveals the enforcing issue faced by the state DOTs.
- Popular scheduling tool includes Primavera products and Microsoft products.
- Delay before starting work in the field generally do not impact the original duration of the project.
- Contractors do not feel the need for a dedicated person as a scheduler. But CPM scheduling required skilled person which may impede the benefits of CPM schedules.

Table 5.2 Summary of the online questionnaire surveys

Topic focused on the survey	DOTs	RCEs	Contractors	Summary
Scheduling technique preferred	Q2, Q9	-	Q6	• Almost all the state DOTs use CPM method of scheduling. One of the popular method of scheduling among DOTs along with CPM is Gantt charts. • Among the contractors Gantt chart and Milestone charts scheduling method are more popular than CPM.
Selection of projects for CPM schedule	Q3	Q2	-	• The top two reasons for selecting projects for CPM schedule from DOT and RCEs viewpoint are: complexity and risks associated with projects. • There is difference on opinion between DOTs and RCEs in the third reason for the selection criteria. DOTs selected total bid amount though RCEs selected total duration of the projects.
Contract requirements / specifications of CPM scheduling	Q4, Q5, Q7	-	Q2	• Most of the DOTs require CPM specification for each project. In most cases, these specifications are a standard one but there are few exceptions. • The contractors also acknowledged that they find specification for CPM schedules in the contracts. • Most of the contractors (two-thirds of responding contractors) prepare CPM schedules even though the requirement is waived in the specification. • DOTs do not necessary request for cost-loaded or resource-loaded or both information loaded schedules from the contractors.
Scheduling software used/preferred	Q6, Q11, Q12, Q13	-	-	• The preferred software among DOTs are the different versions of Primavera P6 products for CPM scheduling. • Besides other software like MS Project, Asta Powerproject are also used. • Some DOTs also have customized forms for scheduling. These forms provide more control over the projects.
Decision making		Q3	Q4	• Both the RCEs and contractors use CPM schedules for decision making.

Topic focused on the survey	DOTs	RCEs	Contractors	Summary
				• RCEs consult schedule occasionally while contracts consult it more frequently.
Storage and Access of schedule database	Q8, Q14, Q17	-	-	• Only a few DOTs store its schedule database on the cloud. • Most of the DOTs are unsure about the cloud storage of its database in next five years. • DOTs have a restrictive mindset in allowing access to its schedule database.
Effort made to follow CPM schedule	-	Q4	-	• In evaluating contractors' efforts to use CPM use, more than one-fourth of RCEs perceive that contracts do not make enough attempts to follow CPM schedules.
Use of CPM schedule (planning, claim analysis, revisions of CPM etc.)	Q16	Q5, Q10	Q3, Q7, Q8	• The most unanimously agreed reason to use CPM schedule other than scheduling is assessing claims. • Most of the contractors maintain a separate CPM schedules for work along with contract specified schedule. • Though the importance of CPM schedules among contractors are acknowledged, a significant fraction of RCEs perceive that the contractors do not make sufficient effort to follow the CPM schedule for project management.
Project extension / Delay associated with CPM schedule	-	Q6, Q7, Q8, Q9	-	• Most of the RCEs indicate that the time between NTP and first start of work do not impact the project delay. • Most of the RCEs agree that the majority of the change orders of the project occurs in the last third of the projects. But they also think that a CPM schedule do no help in reducing the number of change orders. • Contract modification is identified as the major cause of project extension by the RCEs, followed by weather and change orders from owners. Also, 'utility conflicts' is another reason identified for project extension.

Topic focused on the survey	DOTs	RCEs	Contractors	Summary
Schedulers requirements and tasks	-	-	Q9, Q10, Q11	• Most contractors do not have a dedicated person for scheduling. Scheduling is performed by either in-house only or combination of in-house and outside consultant. • The schedulers not only perform the task of scheduling but also executes other tasks such as administration, cost estimation, supervision etc.
Cost of CPM application	-	-	Q5	• From contractors' perspective, the cost of CPM schedule rarely exceeds 2.5% of the total cost of the project.
Value of CPM for success of the company	-	-	Q12	• The average rating for the value of CPM is 2.1 (scale 1 to 4, 1 being very important) from the contractors' perspective. It shows that contractors recognize CPM schedule as important but not evident yet.

5.4 Chapter Summary

This chapter provide insights on the findings from the statistical analysis and online questionnaire survey. The statistical analysis reveal that CPM schedules have association for particular project types, districts, size, and duration groups but not for all. The surveys reveal some of the issues like enforcing the use of CPM schedules, sophisticated risks analysis as selection criteria, and need of a skilled scheduler.

CHAPTER 6: CONCLUSIONS

The analysis and results provided in Chapter 4 and 5 gives insight on the general characteristics of project data in South Carolina, associations between fraction of delayed projects and use of CPM schedules, and the impact of a CPM schedule on the risk of delay.

The type of project has an influence on whether the requirement for a CPM schedule is waived. Paint and marking, sign and signal, guardrail, drainage structure and landscape projects are not generally associated with a CPM schedule in the South Carolina data. In regard to delay after original contract completion date, the project types with a significant fraction of the total number of project (i.e. HMAS, GNRL) show a marked increase in the fraction of delayed projects when a CPM schedule is provided to the DOT. Statistically significant relationships between mean delay and CPM scheduled projects exists for some project types (i.e., HMAS) but not for all.

After considering adjustments due to change orders (CO_Delay), fewer scheduled projects have delays compared to when the delay is measured using original contract completion date (TT_Delay). However, Chi-Squared testing revealed that the number of scheduled projects and CO_Delay are independent for all project types. Statistically significant associations between the number of scheduled projects and CO_Delay were found for District 5 (SSPRIM: 4.35% vs SSNULL: 11.72%) and large-sized projects (SSPRIM: 16.14% vs. SSNULL: 24.52%).

Three project types: BRDG, GNRL and HMAS have statistically significant difference in mean delay after original completion date for scheduled and unscheduled projects. In addition, small sized projects show the statistically significant difference but for mean delay after adjusted completion date. Finally, change order schedule adjustments are more effective in reducing CO_Delay with projects using CPM.

Considering the widespread use of CPM, the finding of an increased fraction and length of project delay with the use of CPM scheduling was unexpected by the authors. We conjecture that one or more of the following are occurring:

- Construction personnel are not using CPM scheduling properly.
- The use of CPM provides an unwarranted belief that the project will be delivered on time until late in the project.
- Having a CPM schedule does not automatically allow one to manage all the risks associated with construction projects and mitigate delays.
- There was an unidentified selection bias of waving CPM schedules for project with less risk of delay.

Additional research is needed to verify if one of the reasons contributed to the ineffectiveness of CPM scheduling. The survey of state DOTs, RCEs and contractors reveals some of the key issues regarding the use of CPM:

- *Selection Criteria:* The CPM schedules are selected based on the perceived complexity and risks, generally measure in terms of project size and duration. More sophisticated risk analysis should be incorporated in the selection criteria.

- *Enforcing:* Specifications for schedule do not necessarily request cost/resource loaded schedules. A resource loaded schedule will help the DOT personnel to review the schedule that represent practical situations. Hence, regular updates and review should be enforced.
- *Scheduler:* CPM schedules requires skilled person to implement correctly. Most of the contractors do not employ a dedicated scheduler in their workforce. As a result, the full potential of CPM schedules is not put into practice.

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APPENDIX – A: EVALUATION OF CONSTRUCTION STANDARD SPECIFICATIONS OF DOT

Symbols, abbreviations and its meaning:

✖	Not required
◣	Required for some projects
■	Required for all projects
●	Required fulfilling one of the formats of scheduling
CPM	Critical Path Method
PSC	Progress Schedule Chart
TSLD	Time-Scaled logic diagram
AC/ASC	Activity Chart/ Activity Schedule chart
WN	Written narration
ND	Network diagram

DOT	Scheduling technique required/ preferred/ used by state DOT							Required software to use	Payment method	Designated Scheduler Required
	Bar Chart	CPM	PSC	TSLD	AC or ASC	WN	ND			
ALABAMA	◣	◣								
ARIZONA	●	●								
ALASKA		■								
ARKANSAS										
CALIFORNIA		■						Primavera P6	Paid for CPM	
COLORADO	◣	■						Primavera product; MS Project	Incidental to work item	
DELAWARE		■							Incidental to work item for PSC; Paid item for CPM	
DISTRICT OF COLUMBIA								Primavera Product; Other, approved by engineer		
FLORIDA		■								
GEORGIA		■						Form, prescribed by engineer		
HAWAII				■				Primavera SureTrak;		

								Other, specified in the contract		
ILLINOIS		●	●					Primavera SureTrak; MS Project		
IDAHO	■	■		■					Incidental to work item	
INDIANA	◣								Paid for the Item	
IOWA		■						Computer developed schedule; Other, approved by engineer	Incidental to work item	
KANSAS			■				◣		Incidental to work item	
KENTUCKY	◣	◣				■				
LOUISIANA	■									
MAINE		■							Incidental to work item	
MARYLAND		■			■				Incidental to work item for AC; Paid item for CPM	YES
MASSACHUSETTES										
MICHIGAN		◣	■					Form (1130) prescribed by the Department	Incidental to work item	
MINNESOTA	■	◣						Primavera P6		

MISSISSIPI		■						Form prescribed by the Department		
MISSOURI										
MONTANA		◣			■			Primavera P6; Any Primavera Product	Paid for the Item	
NEBRASKA		■								
NEVADA	●	■		●				Any Primavera product		
NEW HAMPSHIRE	◣	■						Primavera Product; MS Project	Incidental to work item	
NEW JERSY									Paid for the Item	
NEW MEXICO	◣	■						Computer developed schedule; Other, directed by the Department		
NEW YORK		◣							No payment (contractor’s obligation)	
NORTH CAROLINA				■				Form prescribed by the Department		
NORTH DAKOTA	■	◣						MS Project	Paid for the Item	
OKLAHOMA		◣			■					

OREGON	■	◣						PRIMAVERA P3/ SureTrak / other approved ; MS Project		
OHIO	■								Incidental to work item	
PENNSYLVANIA		■						Asta Powerproject or compatible	Paid for the CPM	
RHODE ISLAND		■								
SOUTH DAKOTA										
TEXAS	■	■							Incidental to work item	YES
TENNESSEE	◣	◣						Computerized Schedule software for some projects		
UTAH		■						Primavera P6	No payment (contractor’s obligation)	
VEMONT		■								
VIRGINIA	◣							Primavera Product	Incidental to work item	
WEST VIRGINIA		◣			◣					
WISCONSIN	■	◣						Computer developed schedule; Other, directed by the Department		

WASHINGTON	◣	◣								
WYOMING	■	◣						Primavera P6	Incidental to work item for bar chart; Paid for CPM	

APPENDIX – B: RESULTS OF STATISTICAL ANALYSIS OF PROJECT TYPES

TYPE		TOTAL	Unscheduled Projects (SSNULL)				Scheduled (SSPRIM) projects				Chi-square test				Student's t-test			
			CO_DELAY		TT_DELAY		CO_DELAY		TT_DELAY		CO_DELAY		TT_DELAY		CO_DELAY		TT_DELAY	
			Delay	No delay	Delay	No delay	Delay	No delay	Delay	No delay	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value
ALL		2097	939				1158											
	Number of projects		151	788	446	493	168	990	629	529								
	Percentage of project (%)		16.08%	83.92%	47.50%	52.50%	14.51%	85.49%	54.32%	45.68%	0.87671	0.3491	9.3837	0.00218				
	Mean delay (days)		38.84768		95.6053		32.20238		121.469						-1.1580	0.24769	3.3839	0.00074
	SD		52.30255		106.928		50.13127		143.592									
	Improvement for having a schedule						17.10604		-27.0525									

ASPT		102	50				52											
	Number of projects		10	40	20	30	10	42	18	34								
	Percentage of project (%)		20.00%	80.00%	40.00%	60.00%	19.23%	80.77%	34.62%	65.38%	0	>0.999	0.12777	0.7208				
	Mean delay (days)		44.5		94.4		46.5		81.5						0.0825683	0.93510	-0.4078	0.68580
	SD		52.13284		89.0389		56.11942		105.876									
	Improvement for having a schedule						-4.49438		13.6652									
BRDG		98	21				77											
	Number of projects		2	19	10	11	11	66	48	29								
	Percentage of project (%)		9.52%	90.48%	47.62%	52.38%	14.29%	85.71%	62.34%	37.66%	0.043	0.8357	0.93315	0.334				
	Mean delay (days)		7.5		50.7		27.54545		156.437						1.151707	0.27385	2.90475	0.00531
	SD		3.535534		54.976		23.73072		221.575									
	Improvement for having a schedule						-267.2727		-208.555									
B		10	10				0											

	Number of projects		1	9	5	5	0	0	0	0								
	Percentage of project (%)		10.00%	90.00%	50.00%	50.00%	0.00%	0.00%	0.00%	0.00%	6.4	0.01141	0	>0.999				
	Mean delay (days)		45		87.2		0		0									
	SD																	
	Improvement for having a schedule																	
CGSW			111				42											
	Number of projects		17	94	45	66	6	36	19	23								
	Percentage of project (%)		15.32%	84.68%	40.54%	59.46%	14.29%	85.71%	45.24%	54.76%	1.25E-31	>0.999	0.117	0.7323				
	Mean delay (days)		32.41176		75.9777		18.5		66.1578						-0.65963	0.51665	-0.0469	0.64004
	SD		48.134		79.1671		29.50763		69.0766									
	Improvement for having a schedule	153					42.92196		12.9246									
DRST			11				2											
	Number of projects		3	8	5	6	0	2	1	1								
	Percentage of project (%)	13	27.27%	72.73%	45.45%	54.55%	0.00%	100.00%	50.00%	50.00%	5.20E-32	>0.999	9.92E-32	>0.999				

	Mean delay (days)																	
	SD																	
	Improvement for having a schedule																	
GDRL			83				2											
	Number of projects		3	80	61	22	0	2	0	2								
	Percentage of project (%)		3.61%	96.39%	73.49%	26.51%	0.00%	100.00%	0.00%	100.00%	6.19E-31	>0.999	0.000831	0.977				
	Mean delay (days)				121.459				166								0.68925	0.49327
	SD				88.7783				142.835									
	Improvement for having a schedule	85							-36.6716									
GNRL			109				195											
	Number of projects		12	97	53	56	27	168	108	87								
	Percentage of project (%)		11.01%	88.99%	48.62%	51.38%	13.85%	86.15%	55.38%	44.62%	0.28148	0.5957	1.0258	0.3112				
	Mean delay (days)	304	29.91667		86.56604		47.14815		153.7593						2.771327	0.009	3.076476	0.002457

	SD		30.80867		89.96378		91.13376		187.1541									
	Improvement for having a schedule						-57.59827		-77.6208									
HMAS		1007	243				764											
	Number of projects		40	203	83	160	113	651	423	341								
	Percentage of project (%)		16.46%	83.54%	34.16%	65.84%	14.79%	85.21%	55.37%	44.63%	0.28009	0.5966	32.333	1.30E-08				
	Mean delay (days)		34.225		70.87952		28.81416		1143.111						-0.7659466	0.444904	3.024782	0.002
	SD		42.0119		105.4761		37.05463		121.5155									
	Improvement for having a schedule						15.81961		-60.9931									
LDSC		13	12				1											
	Number of projects		0	12	9	3	0	1	1	0								
	Percentage of project (%)		0.00%	100.00%	75.00%	25.00%	0.00%	100.00%	100.00%	0.00%	9.3077	0.002282	4.07453-30	>0.999				
	Mean delay (days)																	
	SD																	

	Improvement for having a schedule																	
PCCP		14	6				8											
	Number of projects		0	6	4	2	0	8	2	6								
	Percentage of project (%)		0.00%	100.00%	66.67%	33.33%	0.00%	100.00%	25.00%	75.00%	0.28571	0.593	1.0269	0.3109				
	Mean delay (days)				95.75				147								1.33664	0.252301
	SD				45.30912				41.01219									
	Improvement for having a schedule								-53.5248									
PMEP		21	21				0											
	Number of projects		9	12	11	10	0	0	0	0								
	Percentage of project (%)		42.86%	57.14%	52.38%	47.62%	0	0	0	0	0.42857	0.5127	0.014762	0.8273				
	Mean delay (days)																	
	SD																	
	Improvement for having a schedule																	

PMPT			21				0											
	Number of projects		2	19	6	15	0	0	0	0								
	Percentage of project (%)		9.5 2%	90. 48 %	28. 57 %	71. 43 %	0	0!	0	0	13.7 62	0.000 2075	3.857 1	0.049 53				
	Mean delay (days)																	
	SD																	
	Improvement for having a schedule	21																
PMRP			88				1											
	Number of projects		14	74	35	53	0	1	0	1								
	Percentage of project (%)		15. 91 %	84. 09 %	39. 77 %	60. 23 %	0.00 %	100 .00 %	0.0 0%	100.0 0%	4.17 E- 31	>0.99 9	4.47 E-30	>0.9 99				
	Mean delay (days)																	
	SD																	
	Improvement for having a schedule																	
PMTH		89	104				4											
	Number of projects		32	72	68	36	0	4	1	3								
	Percentage of project (%)		30. 77 %	69. 23 %	65. 38 %	34. 62 %	0.00 %	100 .00 %	25. 00 %	75.00 %	0.58 456	0.444 5	1.253 8	0.262 8				
	Mean delay (days)	108																

	SD																	
	Improvement for having a schedule																	
SGNL		47	39				8											
	Number of projects		4	35	24	15	1	7	5	3								
	Percentage of project (%)		10.26%	89.74%	61.54%	38.46%	12.50%	87.50%	62.50%	37.50%	6.4E-30	>0.999	6.3E-31	>0.999				
	Mean delay (days)				195.7917				60								-1.8998	0.06818
	SD				154.9404				68.20924									
	Improvement for having a schedule								69.35518									
SIGN	12	12	10				2											
	Number of projects		2	8	7	3	0	2	1	1								
	Percentage of project (%)		20.00%	80.00%	70.00%	30.00%	0.00%	100.00%	50.00%	50.00%	6.25E-32	>0.999	2.63E-31	>0.999				
	Mean delay (days)																	
	SD																	
	Improvement for having a schedule																	

APPENDIX – C: ONLINE QUESTIONNAIRE SURVEY RESULTS

SURVEY OF STATE DOTs ON CPM SCHEDULE

1. Which agency do you represent (e.g., South Carolina DOT)?

A total of 23 responses (out of 50, 46%) were received from the state dot headquarter personnel.

2. Do you use Critical Path Method (CPM) for project management?

	Count	Percentage
Yes	22	95.65%
No	1	4.35%
	23	

3. How do you select projects for CPM scheduling? (select all that apply)

	Count	Percentage
Based on complexity of the project	16	72.3%
Based on risk associated with the project	12	54.5%
Based on total bid amount of the project	6	27.3%
Following the rules and regulations of the agency	5	22.7%
Other…	6	
• Based on contract special provision • Incentive/ disincentive • CPM for all projects • Contractor option		
Total	22	

4. Do you require CPM specifications for each project? (i.e. ensures least interference with traffic, employ sufficient labor and equipment at all times, use of certain methods or equipment, etc.)

	Count	Percentage
Yes, for all projects	8	36.4%
Yes, for most of the projects	3	13.6%
Yes, for some of the projects	8	36.4%
No	3	13.6%
	22	

5. Are specifications for scheduling the same for all projects or customized for each project?

	Count	Percentage
Standard, for all projects	11	50.00%
Standard, for most of the projects (customized for some projects)	7	31.82%
Customized, for all projects	4	18.18%
	22	

6. What software does your agency currently use for scheduling? (select all that apply)

	Count	Percentage
Primavera P6 , version 15 or newer	6	27.3%
Primavera P6 , version 8 (8.1, 8.2, 8.3, 8.4)	11	50%
Primavera P6 , version 7 or older	4	18.2%
Primavera P3	2	9.1%
SureTrak	0	-
Microsoft Project 2010	3	13.6%
Microsoft Project 2013	1	4.6%
Microsoft Project 2016	3	13.6%
Other		
• Asta Powerproject • Paper • Contractor preference		
	22	

7. What types of information are loaded with schedules?

	Count	Percentage
Resource	5	22.7%
Cost	2	9.1%
Both (resource and cost)	6	27.3%
None	5	22.7%
Other…	4	18.2%
• Activities • Project specific calendar • Conditional resource loading • (i.e. project > 7.5 mill)		
	22	

8. Do you currently host your schedule database on the cloud?

	Count	Percentage
Yes	3	13.6%
No	19	86.4%
	22	

9. Do you have plans to move your database to the cloud in the next five years?

	Count	Percentage
Yes	2	9.1%
No	7	31.8%
Maybe	10	45.5%
No response	3	13.6%
Total	22	

10. What scheduling technique do you use other than CPM? (select all that apply)

	Count	Percentage
CPM only	8	36.4%
Gantt charts	11	50.0%
Milestone charts	3	13.6%
Other…		
• Bar Charts (Excel) • TxDOT standard specs item 8.5 • Monitoring charts		
	22	

11. What software is used for Gantt charts scheduling technique? (i.e. Excel, pen/paper)
12. What software is used for Milestone charts scheduling technique? (i.e. Excel, pen/paper)
13. What software is used for "other" scheduling technique? (i.e. Excel, pen/paper)

- MS Excel
- Asta powerproject
- MS Word
- Pen-paper
- DOT provide contractor the option to choose their desired software.
- DOT specific form is used for milestone charts

14. Do you allow contractors to access your schedule database?

	Count	Percentage
Yes	3	13.6%
No	17	77.3%
Depends on the contract	2	9.1%
	22	

15. In what situations do you require a revised CPM schedule? (select all that apply)

	Count	Percentage
Critical path changes	21	95.5%
Change orders	14	63.6%
Resource unviability	4	18.2%
Other…		
• Activity original duration changes • Monthly updates • Mandatory monthly updates • Contract time changes • Contractor deviates from current progress schedule • Project behind schedule greater than certain days (i.e. 10 days) • Time extension require for revised CPM		

16. Do you use CPM for assessing claims?

	Count	Percentage
Yes, for all claims	9	40.9%
Yes, for selected claims	13	59.2%
No	0	0.00%
	22	

17. If your agency has any documents related to construction project management and practice that can be shared, please provide a link below or email a copy to the PI of the project (Dr. Robert L Mullen) at rlm@sc.edu

18. If you would like to receive a copy of the survey results, please provide an email address

19. Thank you for taking time out to participate in our survey. During our research, we may find it helpful to follow up with you for additional information, please provide an email or phone number for us to contact you for follow-up questions

SURVEY OF RESIDENT CONSTRUCTION ENGINEERS ON CPM SCHEDULE

1. Which agency do you represent (e.g., South Carolina DOT)?
2. If you have the authority, how would you select projects for CPM scheduling? (select all that apply)

	Count	Percentage
Based on complexity of the project	47	92.2%
Based on risk associated with the project	31	60.8%
Based on total duration of the project	27	52.9%
Based on total bid amount of the project	20	39.2%
Based on the previous experience with similar type of work/contractor	21	41.2%
Following the rules and regulations of the agency/client	7	13.7%
Other…		
All projects require CPM anticipated conflicts Time incentives		
Total	51	

3. How often do you refer to CPM (Critical Path Method) schedule for decision making on projects?

	Count	Percentage
Frequently	10	19.6%
Occasionally	34	66.7%
Never	7	13.7%
Total	51	

4. Do you find contractors strive to follow CPM schedule?

	Count	Percentage
Yes, for all projects	0	-
Yes, for most of the projects	11	21.6%
Yes, for some of the projects	25	49.02%
No	15	29.4%
Total	51	

5. If not required by the contract, do contractors still use a CPM schedule?

	Count	Percentage
Yes, all	0	-
Yes, most of the contractors	2	3.9%
Yes, some of the contractors	26	50.9%
No	23	45.1%
Total	51	

6. Do you find the duration between the Notice to proceed (NTP) and start of work in construction projects consume a significant fraction of the total duration of the project?

	Count	Percentage
Yes, for all projects	1	1.96%
Yes, for most of the projects	6	11.76%
Yes, for some of the projects	22	43.14%
No	22	43.14%
Total	51	

7. Do you observe a significant fraction of the change orders from contractors in the last third of the project?

	Count	Percentage
Yes, for all the projects	1	1.96%
Yes, for most of the projects	9	17.7%
Yes, for some of the projects	25	49.02%
No	16	31.4%
Total	51	

8. What are the most common reasons for requesting project extension? (select all that apply)

	Count	Percentage
Weather	34	66.7%
Contract modifications	36	70.6%
Resource constraints	5	9.8%
Inadequate planning and scheduling	16	31.4%
Change orders by owner	29	56.9%
Delay in approving drawing and materials by owner	1	1.96%
Slowness in decision making process	9	17.7%
Other…		
• Inadequate planning and scheduling • by contractor but blames scope of work • Inadequate plans • Utilities • Utility conflicts • Utility Delays • Utility Relocations • Utilities/ Permitting		
Total	51	

9. From your observations, does the use of a CPM schedule reduce the number of change orders in projects?

	Count	Percentage
Yes, for all projects	0	-
Yes, for most of the projects	6	11.8%
Yes, for some of the projects	14	27.5%
No	31	60.8%
	51	

10. Do you use CPM for assessing claims?

	Count	Percentage
Yes, for all claims	16	31.4%
Yes, for selected claims	25	49%
No	9	17.6%
No response	1	
	51	

11. If you would like to receive a copy of the survey results, please provide an email address
12. Thank you for taking time out to participate in our survey. During our research, we may find it helpful to follow up with you for additional information, please provide an email or phone number for us to contact you for follow-up questions

SURVEY OF CONTRACTORS ON CPM SCHEDULE

1. Which state is your company/organization registered in? (e.g., South Carolina)
2. Do you find contracts now contain specifications requiring CPM (Critical Path Method) schedule?

	Count	Percentage
Yes, always	3	6.7%
Yes, most of the time	17	37.8%
Projects greater than $5 million	13	28.9%
Projects greater than $10 million	5	11.1%
Projects greater than $20 million	1	2.2%
Projects greater than $50 million	2	4.4%
Projects greater than $100 million	0	-
Rarely	3	6.7
No	1	2.2%
Total	45	

3. If not required (or, if waived in the contract), do you still prepare a CPM schedule?

	Count	Percentage
Yes	30	66.7%
No	15	33.3%
	45	

4. How often do you make decisions based on CPM schedule?

	Count	Percentage
Frequently	20	44.4%
Occasionally	17	37.8%
Never	8	17.8%
	45	

5. On average, what is the cost of CPM application as a percentage of the total project cost?

	Count	Percentage
Below 0.5%	29	64.4%
0.5% - 2.5%	12	26.7%
Above 2.5%	4	8.9%
	45	

6. Do you use scheduling techniques other than CPM for project management? (select all that apply)

	Count	Percentage
CPM only	13	29.9%
Milestone charts	22	48.9%
Gantt charts	26	57.8%
Other…		

• Excel • Short term schedule • 3 week look ahead • 2 week look ahead • Line chart • Bar chart		
	45	

7. Do you maintain a separate schedule for work in addition to the contract specified schedule?

	Count	Percentage
Yes, for all projects	11	24.4%
Yes, for most of the projects	8	17.8%
Yes, for some of the projects	15	33.3%
No	11	24.4%
	45	

8. Do you use CPM for assessing claims?

	Count	Percentage
Yes, for all claims	5	11.1%
Yes, for selected claims	32	71.1%
No	6	13.3%
No response	2	4.4%
	45	

9. Is your CPM scheduling performed by:

	Count	percentage
In-house personnel	25	55.6%
Outside consultant	2	4.4%
Combination of in-house and outside consultants	18	40%
	45	

10. Do you have a dedicated person responsible for planning and scheduling?

	Count	percentage
Yes	13	28.9%
No	32	71.1%
	45	

11. What other duties does your scheduler perform?

	Count	percentage
Schedule only	6	13.3%
Cost estimation	24	53.3%
Project management other than scheduling	32	71.1%

Administration	12	26.7%
Other…		
• Engineering • Supervision • Surveying • Project Manager/ someone from project team does CPM training organizer • Do mostly scheduling and updates		
Total	45	

12. How important is CPM scheduling for the future success of your company?

	Count	percentage
1 (Very Important)	16	35.6%
2	7	15.6%
3	12	26.7%
4 (unsure)	8	17.8%
No response	2	4.4%
	45	

13. If you would like to receive a copy of the survey results, please provide an email address
14. Thank you for taking time out to participate in our survey. During our research, we may find it helpful to follow up with you for additional information, please provide an email or phone number for us to contact you for follow-up questions