

AUTOMATED PRODUCTIVITY BASED SCHEDULE ANIMATION
(APBSA)

DISSERTATION

Submitted in Partial Fulfillment

of the Requirements for the

Degree of

DOCTOR OF PHILOSOPHY (Civil Engineering)

at the

POLYTECHNIC INSTITUTE OF NEW YORK UNIVERSITY

by

Gokhan Gelisen, P.E.

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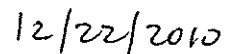
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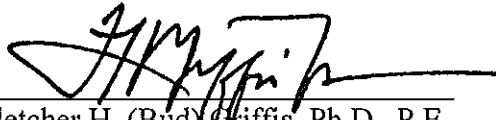
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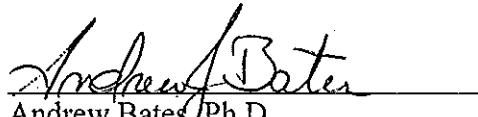
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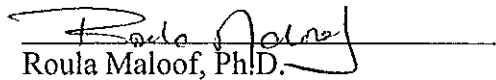
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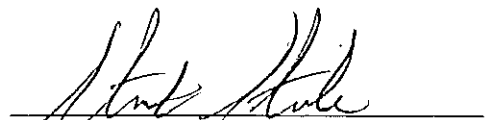
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Vita

Gokhan Gelisen was born on February 19, 1978 in Ankara, Turkey. Mr. Gelisen holds a M.S degree in Computer Science from Columbia University, a M.S degree in Structural Engineering from Lehigh University, and a B.S degree in Civil Engineering from Middle East Technical University. Mr. Gelisen has been in construction industry for more than 10 years. Currently, he is a Cost Manager at Skanska USA Civil Inc. and he is registered as a Professional Engineer in Connecticut, New Jersey, and New York. Mr. Gelisen is currently serving as President of Society of Turkish American Architects, Engineers and Scientists, Inc. He has devoted most of his time to this research from September 2006 to June 2010.

Dedication

To my wife Ayca, and my parents, Yasemin and Orhan.

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The author is deeply indebted to Professor Fletcher H. (Bud) Griffis, for his continued guidance, encouragement and cooperation in this research. The interest of Mr. Buddy Cleveland, Mr. Chet Tabaka and other Bentley Systems, Incorporated staff is gratefully acknowledged. Last but not the least; appreciation is extended to the entire faculty, staff and fellow students in Department of Civil Engineering at Polytechnic Institute of NYU for all their help.

AN ABSTRACT
AUTOMATED PRODUCTIVITY BASED SCHEDULE ANIMATION

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by

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Advisor: F. H. (Bud) Griffis, Ph.D., P.E.

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June 2010

Many studies of construction labor productivity are at a macro level. These macro-level studies attempt to quantify the productivity or changes in productivity over the entire industry or a segment of the industry. This study is aimed at a micro or project-level examination of productivity. The tool developed allows the user to predict, manage and even optimize the productivity associated with a project or levels of projects.

Automated Productivity Based Schedule Animation (APBSA) is a dynamic scheduling methodology that stochastically utilizes weekly trended construction labor productivity data in order to automatically update the baseline schedule that was created at the beginning of a project. APBSA reports the construction activity duration variances and animates the progress of the job with the most current data available in a 4-D environment. Contractors and others can improve their planning by utilizing APBSA with Building Information Modeling (BIM) which will help them to improve their craft productivity.

As a case study, the three-story Systems Engineering Facility III at Hanscom Air Force Base (AFB) was modeled. The model was developed in order to demonstrate the impacts of time and cost-based stochastic productivity indices on the baseline schedule. A time-cost trade-off analysis was also performed in order to show effects of duration variations on the cost of the project.

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CHAPTER 1: INTRODUCTION

There is considerable competition in today's construction industry. For some contractors, it seems that there is always another contractor who is willing to perform the same job for a lower price. The ability to minimize time and costs of a project could determine level of success of a contractor in market-driven economies. Contractors cannot remain competitive without effectively managing time and costs of resources in today's highly competitive business environment. Not only must contractors lower their prices to win the bids, but they may be subject to aggressive schedules and face possible delay damages. One tool that contractors have to alleviate these conditions is to improve the productivity of their labor.

Although many contractors keep records of their labor productivity and have developed methodologies to utilize that data, there is no commercially available stochastic system that estimates future activity productivity by factoring in real-time information to update a proposed schedule.

Automated Productivity Based Schedule Animation (APBSA) is a dynamic scheduling system that stochastically utilizes weekly trended construction labor productivity data in order to automatically update a schedule. APBSA calculates the construction activity duration variances and generates an animation of the progress of the work in a 4-D environment.

APBSA imports the construction labor productivity data, anticipated quantities and remaining quantities of the trended activities from a contractor's database. Contractor is generically used to represent any entity that prepares the schedule and performs such

analyses on construction projects. Adjustments are made to the productivity rates utilizing user-defined factors; such as supervision, overtime, and weather conditions. The impact of these factors on labor productivity rates is determined by using a probabilistic analysis approach. APBSA also compares anticipated and remaining quantities from the contractor's database with quantities from CAD model. Finally, APBSA calculates the proposed start and end dates for each construction activity and feeds this data to 4-D visual animation software.

Project Management, Project Controls, Human Resources, Design & Analysis, Procurement, Coordination and 3-D Computer Models are processes which can be incorporated into a Building Information Model. Contractors can utilize Automated Productivity Based Schedule Animation with a Building Information Model as a new process which will help them to improve their craft productivity (Figure 1.1).

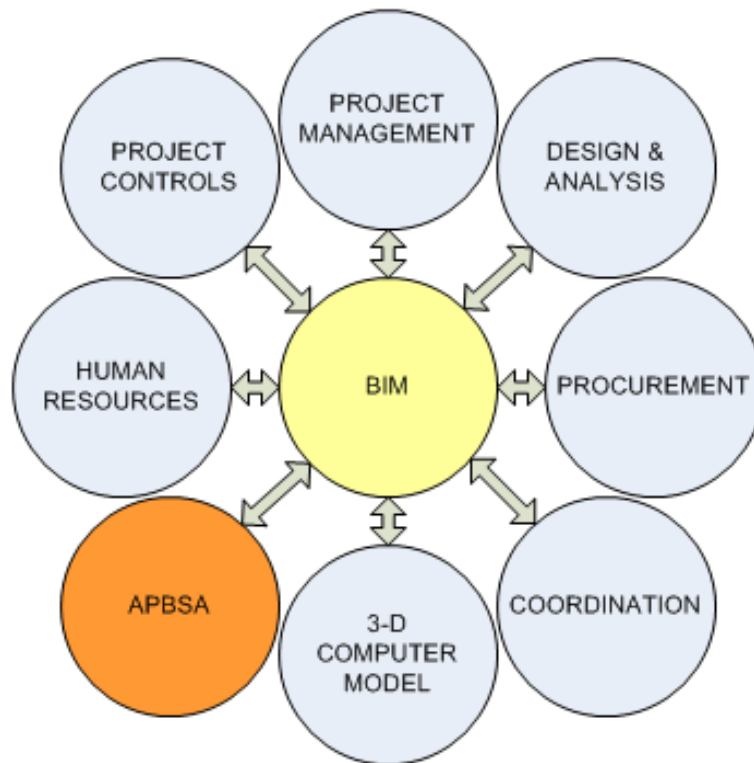


Figure 1.1 APBSA integrated Building Information Modeling Processes

1.1 Background on Craft Productivity

Teicholz (2004) stated that the productivity of the construction industry, as measured by contract dollars of new construction work per work hour, has gradually declined (with some modest exceptions) over the past 40 years at an average compound rate of 0.59%/year while labor productivity in all non-farm industries experienced an increase of 1.77%/year over the same time period. Although construction labor productivity has slightly improved over the past decade, its decline relative to the rest of the non-farm industries has continued [131].

A study conducted on a number of power plant projects in the middle 1970s showed that only 32% of the daily construction activities were utilized in direct work, about 28% was spent in performing support tasks, and about 40% was wasted or idle time [52]. Another study performed on a building constructed by a well respected general contractor demonstrated that only 38% of crew time over several days were utilized in productive work, about 27% was spent in performing contributory tasks, and about 35% was noncontributory tasks [106]. Recent labor utilization measurement results at Cinergy/FWZ Gibson Station Selective Catalytic Reduction (SCR) construction project showed that total productive time, including ‘assisting’ and ‘adjusting equipment’ was 76% [28]. Aforementioned studies show that more than 30% of a worker’s time is wasted and directs attention to management’s responsibilities.

As W. Edwards Deming stated decades ago in reference to the manufacturing industry, two things must happen in the construction industry in order to improve craft productivity [110]:

- The variability of the processes must be reduced (e.g., prefabrication); and

- The level of performance must be raised (e.g., the rebar crew productivity will decrease because of the common use of large diameter bars required in the design.)

A group of owners, contractors and the Michigan Building Trades formed the Michigan Tripartite Committee (MTC) to share plans, problems, and successes with the goal of maximizing through consensus usage of a finite resource base in a cost effective manner. In 2002, the MTC Productivity Task Force defined the following five topics as the greatest barriers to productivity on the construction jobsite [135]:

- Design: specifications, drawings, documents have to be improved;
- Field support for timely responses; have architect/engineer with field competency on site;
- Coordinate Design/Review;
- Timely RFIs/RFPs; and
- Construction/Project management competency.

The same committee defined the following five topics as the Potential for Productivity Improvement (wrench time) [135]:

- Constructability review of the design documents with input of major contractors on schedule quality and realism;
- Coordination among major contractors;
- Pre-project planning;
- Communication and teamwork among owners, design professionals, contractors and labor; and

- Improvement of the construction management process. Considering general contractors along with construction managers.

Picard (2005) listed contractor capabilities, once adopted, that are transferable to raise labor productivity and boost competitiveness as [110]:

- Direct measurement of labor utilization, providing management with key performance indicators for benchmarking and performance-based incentive contract language;
- Top-down “raise-the-bar” continuous improvement strategy to actively innovate and improve the construction work process toward greater value fulfillment; and
- Organizational training and learning to create project-wide awareness of working efficiently.

Sanvido (1988) cited ineffective management as the primary cause of poor productivity rather than an unmotivated and unskilled force [54, 95, and 118].

Management performs the following main tasks:

- Planning;
- Resource supply and control;
- Supply of information and feedback; and
- Selection of the right people to control certain functions.

Picard (2005) stated that project managers must be capable of managing three interrelated areas of influence to achieve project success [110]:

- Getting actionable information about process performance;
- Setting policies to effectively control the construction process; and
- Minimizing buffers that protect against stop-and-go variability.

Daneshgari (2006) identified four areas in which construction planning is necessary to manage effectively a project [30]:

- Estimate hand-off to project management;
- Job layout and value engineering;
- Procurement planning; and
- Job kickoffs (three-day-look-ahead-short-interval scheduling):
 - o Small;
 - o Well defined;
 - o Measurable pieces reflecting the way the technicians view job progress;
 - o Visible; and
 - o Tangible areas such as one room, one area, one wing, one phase, one operation at a time.

Moselhi, Assem, and El-Rayes (2005) identified the following factors to influence the impact of change orders on labor productivity based on the field investigation conducted, and comprehensive literature review [99]:

- Change order intensity, including number of change orders, frequency, and ratio of change order hours to contract hours;
- Timing in relation to project duration;
- The differences in the level of skill required to perform the work and its level of complexity and the interference which varies from one type of work to another and among work types;
- Type of impact;
- Project phase (Design/Construction) when change order is proposed; and

- On-site management.

The data and findings cited in The Construction Industry Cost Effectiveness (CICE) Business Roundtable report (1974) on the impact of overtime operation on construction projects and the inflationary effects of such operations have been found still valid and support the following conclusions. Placing field construction operations on scheduled overtime reduces labor productivity; where a work schedule of 60 or more hours per week is continued longer than about two months, the cumulative effect of decreased productivity will cause a delay in the completion date beyond that which could have been realized with the same crew size on a 40-hour week; and where overtime operations are deemed necessary despite productivity losses (for example, on remote construction projects where bachelor housing is provided at the job site and on maintenance turnarounds) proper management can minimize the inflationary effects. Management actions to be considered include use of an additional shift and periodic shutdown of the work for a Sunday or weekend [119].

Lee (2007) summarized all comparable data, excluding that from questionable and duplicate data sources, in Table 1.1.1 to illustrate the overall trends in overtime productivity impacts on a straight-time period (40 hours per week) published by various studies for schedules of 50, 61, and 70 hours per week, respectively. However, Hanna's model was excluded from the average and standard deviation calculations since the choice of total overtime hours to calculate the efficiency values of the model was random [79].

Study or Model	Overtime Schedule (Hours per Week)		
	50	60	70
Adjusted BLS data by MCAA (1968) [90]	92.00%	83.00%	79.80%
O'Connor [Foster Wheeler] (1969) [105]	87.00%	73.00%	-
NECA-Howerton (1969) [70, 101]	-	79.50%	62.50%
BRT [Proctor & Gamble] (1974) [112]	90.00%	85.00%	
Adrian (1987) [7]	88.00%	85.00%	72.50%
Bromberg (1988) [18]	93.00%	80.00%	
NECA (1989) [102]	89.00%	83.00%	70.00%
Haneiko and Henry (1991) [55]	-	92.00%	-
Thomas and Raynar [CII] (1994) [132]	88.00%	-	-
Hanna et al. (2005) [56]	90.00%	81.00%	71.00%
Average (excluding Hanna)	89.60%	82.60%	71.20%
Standard Deviation (excluding Hanna)	2.20%	5.50%	7.10%

Table 1.1.1 Gross Comparison of Impact Data from Various Studies [79]

Depressed real wages and technological advances appear to be the two biggest reasons for the increase in productivity in the 1980's and 1990's. Haas, Borchering, Allmon, and Goodrum (1999) estimated that union labor declined from approximately 70% of the construction work force in the 1970s to 20% in the 1990s [54].

Hasegawa (2006) explained that automation and robotization in the construction industry is farther behind the manufacturing industry because contractors move each time to different sites, building structure members are big and heavy, and most construction operations are performed outdoors. Consequently, the productivity of the construction industry is lower than that of manufacturing industry [60].

Thomas and Smith (1990) presented a productivity forecasting model that summed up the impacts of several disruption factors to account for productivity losses. They summarized various productivity factors and quantified the disruption indices caused by these factors based on three studies conducted at the Pennsylvania State University (Table 1.1.2), which followed the same standardized procedures: Sanders et al. (1989), Bilal and Thomas (1990), and Bennett and Thomas (1990) [79].

Types of Disruption and Corresponding Disruption Indices	Disruption Indices		
	Sanders et al. (1989) [117]	Bilal & Thomas (1990) [15]	Bennett & Thomas (1990) [13]
Normal	1	1	1
Weather Events	0.32	0.34	0.53
Congestion	0.35	0.29	0.3
Sequencing	0.25	0.2	0.27
Materials	0.54		
Storage Area Organization		0.16	
Material Handling and Distribution		0.43	
Material Availability		0.13	
Tool Availability		0.38	
Equipment Availability		0.51	
Rework	0.41	0.21	
Supervision	0.59		
Staffing	0.58	0.11	
Other	0.21	0.31	0.49
Number of Projects	11	13	1
Number of Data Points	570	258	148
Type of Work	Masonry	Masonry	Concrete Wall Formwork

Table 1.1.2 Impact of Disruptions [133]

Thomas and Smith (1990) also categorized productivity influencing factors into three categories [79]:

- Root Causes of Productivity Loss (Table 1.1.3);
- Design Parameters and Contractor Management as Root Causes of Productivity Loss (Table 1.1.4); and
- Indirect Causes of Productivity Loss (Table 1.1.5).

Factor	Previous Quantitative Studies Reviewed	Weight of Opinion	Descriptions
Weather (Temperature and Humidity)	• NECA (1974) • Koehn and Brown (1985) • Grimm and Wagner (1974) • Thomas &Yiakoumis (1987) • Bracken and Thomas (1990) • Hester and Kuprenas (1987)	• 50% to 70% efficiency loss with adverse weather conditions.	• Type of work being performed is important.
Weather Events	• Clapp (1966) • Thomas et al. (1989) • Smith, Thomas, and Thrun (1989)	In case of a weather event, efficiency is only: • Clapp: 50% • Thomas: 32% • Smith: 51 %	• Adverse weather events include rain, snow, ice, high winds, storm, etc.
Sequencing (Out-of Sequence Work)	Studies at Penn State: • Sanders, Thomas, and Smith (1989) • Bilal and Thomas (1990) • Bennett and Thomas (1990)	• Efficiency loss ranges from 40% to 80%. • 75% loss is common.	
Interruptions and Delays	• Thomas et al. (1989) • Hester and Kuprenas (1987)	• See the original report.	• Studies indicate that productivity and delays may or may not be correlated.
Congestion	• Mobil Oil Data • Smith (1987) • Kappaz (1977) • US Army Corps (1979) • Sanders et al. (1989) showed greatest impact - 50 to 75% efficiency loss.	• N/A	• Minimum of 300ft²/person is required. • The comparison graph is republished in the congestion section of this research.
Rework	• Sanders et al. (1989)	• N/A	• No conclusive data.

Table 1.1.3 Root Causes of Productivity Loss [133]

Factor	Previous Quantitative Studies Reviewed	Weight of Opinion	Descriptions
Constructability (Work Content)	• Sanders et al. (1989) • Thomas et al. (1989) • Ward and Thomas (1984) • Daytner and Thomas (1985)	• N/A: little data.	• Penn State's research shows the size of component is an important factor.
Supervision	• Some studies by social scientists; the list of studies reviewed is not provided.	• N/A	• Most of the studies on supervision effect are flawed and not applicable to construction.
Staffing Practices	• Thomas and Kramer (1987)	• N/A	• The overall impact appears to be minimal.
Presence of Supervision	• Sanders et al. (1989): average loss of efficiency of 41 % when foreman was absent.	• N/A	• Insufficient data for conclusions.
Material Management	• Thomas et al. (1989) • Sanders et al. (1989) • Bilal and Thomas (1990)	• Poor material Storage and handling: 20% loss. • Material Distribution and availability problem: 45% to 85% daily loss.	
Crew Size	• Thomas et al. (1989) • Sanders et al. (1989) • US Army Corps (1979)	• N/A	• No studies of crew size have been reported in the literature. • Insufficient data.
Tools and Equipment	• Several studies reviewed; each considers different aspect of the factor.	• N/A	
Artificial Restraints	• Thomas and Smith (1988)	• N/A (no published information.)	• It was believed artificial constraints inhibit productivity improvement.
Union vs. Nonunion & Financial Incentives	• No specific study reviewed or the list of studies reviewed is not provided.	• N/A	• No relationship is found.

Table 1.1.4 Design Parameters and Contractor Management as Root Causes of Productivity Loss [133]

Factor	Previous Quantitative Studies Reviewed	Weight of Opinion	Descriptions
Overtime	• BRT (1980) • O'Connor (1969) • Kossoris (1944; not 1947) • NECA (1969) • Adrian (1988) • CII (1988) • Mogren and Borcharding (1984)	• N/A	• There is much uncertainty regarding overtime. • Little original data.
Shift Work and Work Schedule	• Same list of studies as overtime.	• N/A	• No available data.
Absenteeism and Turnover	• BRT (1982): observed no productivity losses due to absenteeism.	• No productivity losses.	• No available data. • General acceptance that extended overtime increases absenteeism rates.
Manning Levels	• O'Connor (1969) • Waldron (1968) • Kappaz (1977) • Thomas and Jansma (1985) • Investigation on electricians for a nuclear power plant project - unpublished.	• N/A: research findings are inconclusive.	• Manning levels as a single factor is not significant; rather it triggers other factors. • The unpublished investigation on electricians found no correlations.
Change Orders	• Leonard (1987) • Hester & Kuprenas (1987)	• N/A: no integrated data.	• Change orders trigger other factors.

Table 1.1.5 Indirect Causes of Productivity Losses [133]

1.2 Newtown Creek Wastewater Treatment Plant

The Newtown Creek Wastewater Treatment Plant is the largest of New York City's 14 wastewater treatment plants and is currently undergoing a \$5 billion upgrade [49, 104, and 124]. The original plant was built in 1967 and stands on the heavily industrialized shore of the channel separating Greenpoint, Brooklyn from Long Island City, Queens [71]. The plant is fed by 180 miles of sewers which serve about one million residents in a drainage area of about 15,000 acres [71]. The plant has a capacity to treat 310 mgd (18% of the city's wastewater) during dry weather and a combined (storm and sanitary) 700 mgd during wet weather [5]. The plant upgrade began in 1998 and will be

completed in 2014 [124]. Upgrade work includes a 50% increase of existing treatment tank capacity and secondary treatment of all inflow [124, 134]. The secondary treatment requirements of the Clean Water Act require approximately 85% removal of the organic matter in sewage and disinfection of the treated waste [71]. The Department of Environmental Protection (DEP) and the New York State Department of Environmental Conservation (DEC) announced in January 2010 that the Newtown Creek Wastewater Treatment Plant was meeting the Clean Water Act's pollutant removal standards, three years ahead of schedule [124].

1.3 Activity Duration and Cost Data

One of the objectives of this dissertation is to determine how labor productivity is affected by external influences, some of which are discussed in Section 1.1. Such influences include adequacy of office supervision, field supervision, carpenter foreman, master mechanic, maintenance foreman, labor shop steward, teamsters, offsite yard crew, and survey party. Some of the field operations that influence labor productivity are proper fuel, oil, grease for equipment; maintenance of field office; maintenance and protection of traffic (MPT); temporary access and maintenance; dewatering; and crane support. Finally, there are external influences such as weather conditions (temperature, dewpoint, humidity, pressure, wind speed, gust speed and precipitation) which can not be controlled, but nevertheless may impact labor productivity.

The flowchart in Figure 1.3.1 [47] shows the factors that influence the direct work and the unproductive portion of a typical work hour. Historical data on factors that are shown in red can be obtained from a contractor's trending application. The impact of

these factors on labor productivity is then determined by using the probabilistic analysis approach discussed in Chapter 3.

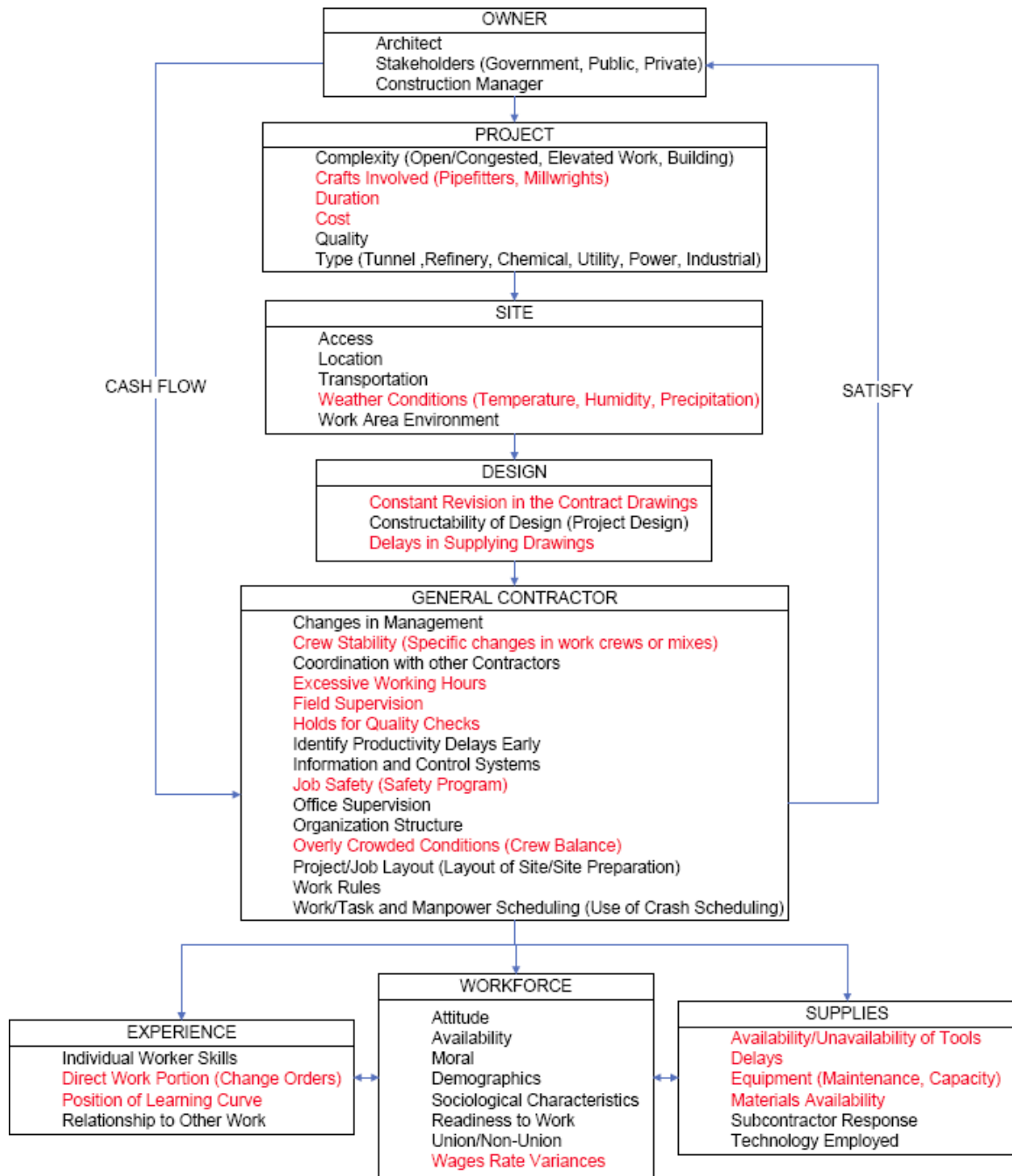


Figure 1.3.1 Factors that Influence the Direct Work & Unproductive Portion of Typical Work Hour

First, preliminary weekly productivities for each activity were determined using the trended cost and duration data from Newtown Creek Water Pollution Control Plant (WPCP) Upgrade.

In order to create a model, several typical construction operations were selected and relevant data pertaining to such work was collected and assembled into correlation matrices. These activities include:

- Forming, reinforcing and placement of concrete;
- Excavation and backfill;
- Cut-off, haul & disposal of piles;
- Concrete demolition;
- Structural and miscellaneous steel work;
- Installation of equipment, pipes and fittings; and
- Architectural work.

In addition, change order and unit price activities were also studied. Weather conditions data, having major influence on labor productivity as discussed in Section 1.1, were also incorporated as explained in the next section.

The next step was to arrive at an average productivity for each activity and evaluate how the productivity was affected by the aforementioned factors as discussed in Chapter 2. Subsequently, the independent variables for the correlation matrix and stochastic analysis were selected and the activities were separated as with or without error. Finally, using the stochastic analysis for the error-free activities, a distribution was determined that can aid in forecasting the labor productivity and the effect of each independent variable on the productivity as discussed in Chapter 3.

1.4 Weather Condition Data

Koehn and Brown (1985) performed a regression analysis in order to derive two mathematical equations relating labor productivity with both temperature and relative humidity, with historical references from Grimm and Wagner (1974), NECA (1974), and Kuipers (1976). The resulting relationship between productivity and temperatures for various degrees of humidity is illustrated in Table 1.4.1 [79].

Kuipers (1976) developed a more complex mathematical model for forecasting efficiency of construction labor in any climate condition. Kuipers augmented the data (Table 1.4.2) either by estimating or by selecting values for parameters such as solar radiation, internal heat production, external mechanical efficiency, the ratio of the effective radiation area of the body to the actual area of the body (f_{eff}), a unit measure to define the clothing's resistance to heat conduction (I_{cl}), and the ratio of the clothed surface of the body to the actual surface of the body (f_{cl}) [79].

Temp (°F)	Relative Humidity (%)									
	5	15	25	35	45	55	65	75	85	95
-20	0.28	0.27	0.25	0.22	0.18	0.13	0.05	-	-	-
-10	0.44	0.43	0.42	0.40	0.38	0.34	0.29	0.21	0.10	-
0	0.59	0.58	0.57	0.56	0.54	0.52	0.49	0.44	0.36	0.23
10	0.71	0.71	0.70	0.70	0.69	0.67	0.65	0.62	0.58	0.50
20	0.81	0.81	0.81	0.81	0.81	0.80	0.79	0.77	0.75	0.71
30	0.90	0.90	0.90	0.90	0.90	0.89	0.89	0.89	0.88	0.87
40	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
60	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.96	0.95	0.93
90	0.95	0.95	0.94	0.93	0.92	0.90	0.88	0.85	0.82	0.78
100	0.81	0.81	0.80	0.79	0.77	0.74	0.71	0.67	0.61	0.54
110	0.58	0.58	0.58	0.57	0.55	0.51	0.47	0.41	0.32	0.21
120	-	0.28	0.28	0.28	0.25	0.21	0.15	0.07	-	-

Table 1.4.1 Construction Productivity as Function of Temperature and Relative Humidity [77]

Climatic Zone	Ambient Temp. (°F)	RH (%)	Wind Speed (mph)	Laborer Efficiency (%)	Solar Radiation (lang/day)	Metabolic Rate (Kcal/hr, m ²)	Mech Eff. (%)	f_{eff}	I_{cl}	f_{cl}
Temperate	0	-	10	40-50	368	220	20	0.72	1.75	1.35
Temperate	30	20	20	60	517		it		1.75	1.35
Temperate	70	40	5	100	523				0.6	1.1
Temperate	90	50	9	60-70	530				0.6	1.1
Temperate	105	30	5	30	564				0.6	1.1
Tropical	75	60	5	90	442				0.6	1.1
Tropical	85	70	20	70	470				0.6	1.1
Tropical	92	78	5	50	474				0.6	1.1
Tropical	98	90	Calm	30-40	436				0.6	1.1
Desert	87	20	Calm	90	647				0.6	1.1
Desert	95	15	15	80	674				0.6	1.1
Desert	120	5	40	0-5	704				0.6	1.1
Desert	125	10	10	10	661				0.6	1.1
Desert	110	40	30	40	608				0.6	1.1
Arctic	40	30	10	90	487				0.7	1.1
Arctic	0	-	2	50-60	437				1.75	1.35
Arctic	-10	-	20	30	358				3.5	1.4
Arctic	-20	-	Calm	30	349				3.5	1.4
Arctic	-40	-	40	0	386				3.5	1.4

Table 1.4.2 Estimated Labor Efficiency for Various Combinations of Temperature, Relative Humidity, and Wind Speed [78]

Because Koehn and Brown's and Kuipers's research [77, 78] proved the significance of the effect of weather conditions on labor productivity, daily historic weather event data (e.g., high temperature, low temperature, high dewpoint, low dewpoint, high humidity, low humidity, maximum pressure, minimum pressure, maximum wind speed, average wind speed, maximum gust speed, and precipitation sum) is incorporated into the present simulation model. Readings from different New York area stations (i.e., MSWUIKBX1, KNYNEWYO46, KNYQUEEN3, KNYBROOK22, KNYQUEEN8, MC9714, MDC007, KNYNEWYO48, and KNYNEWYO17) were compared for accuracy (Figures 1.4.1 and 1.4.2) [140].

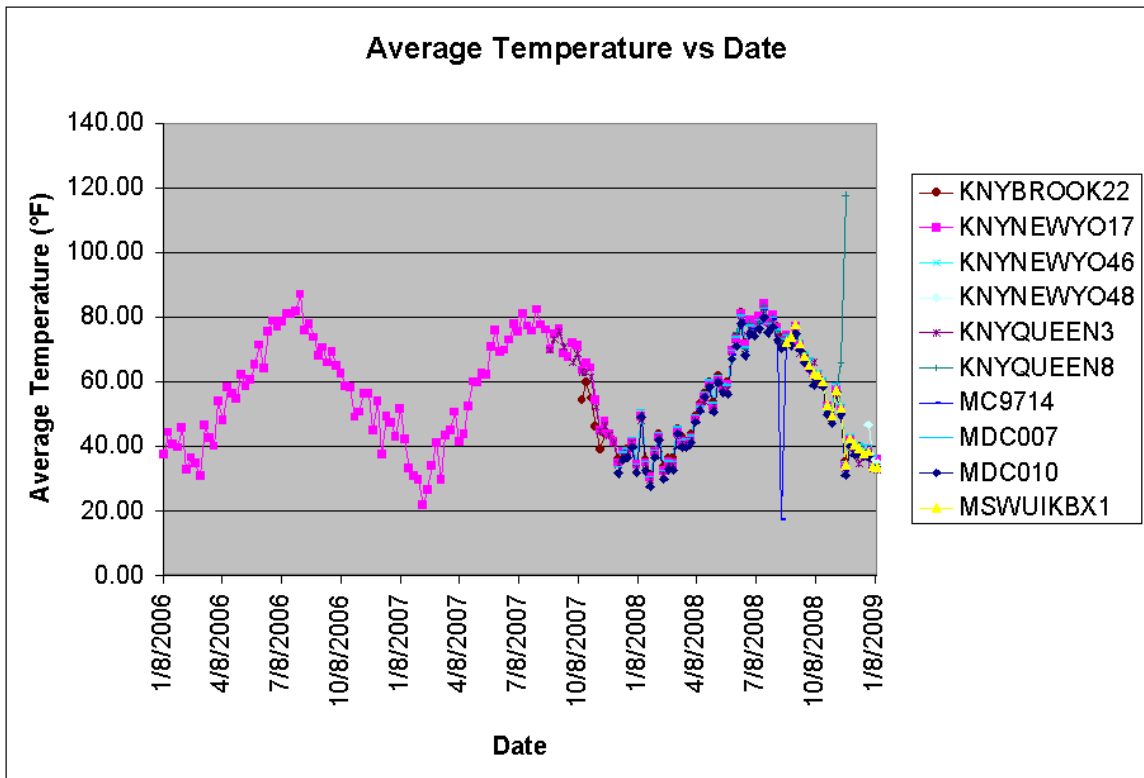


Figure 1.4.1 Average Temperature (°F) versus Date

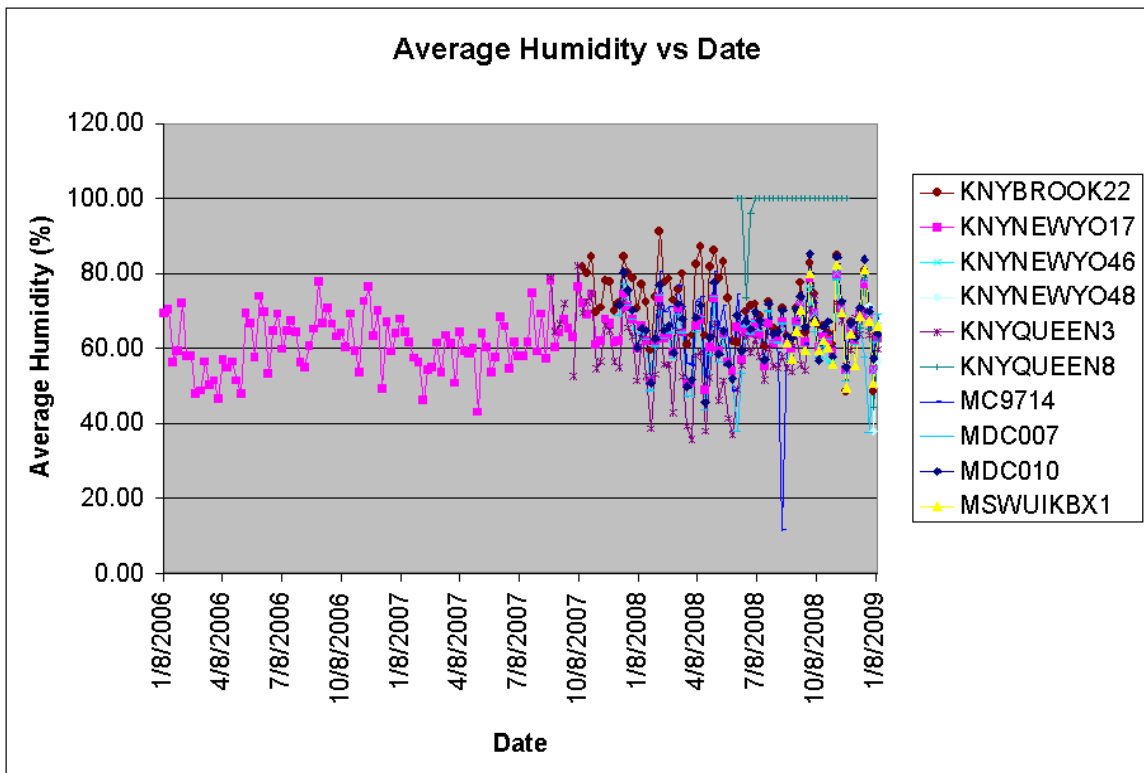


Figure 1.4.2 Average Humidity versus Date

Data from different stations were found to be relatively consistent with a few exceptions (Appendix A.1). Weather event data from station KNYNEWYO17 (Table 1.4.3, Appendix A.2) is used because of the station's proximity to the construction site, and data is available going back to the beginning of 2006 [139]. The station is located at 3-39 River Road New York, NY 10044 (N 40.766074 W 73.946894) and data is captured via a LaCrosse WS-2310 wireless weather station at 10 minute intervals at KNYNEWYO17 [93].

Average Temperature (F)	57.07
Average Dewpoint (F)	43.42
Average Humidity (%)	61.91
Average Pressure (IN)	29.99
Average Windspeed (MPH)	0.54
Maximum Gustspeed (MPH)	21.14
Precipitation Sum (IN)	0.09

Table 1.4.3 Average Weather Event Data from station KNYNEWYO17

CHAPTER 2: QUANTIFYING LABOR PRODUCTIVITY AND THE IMPACT OF CHANGES

Contractors use a variety of existing methods to quantify and predict labor productivity, to determine the relationships among productivity, cost, and duration, calculate productivity indices in order to produce a comparable unit (e.g., cy/hr for concrete, sf/hr for formwork, and cwt/hr for rebar) for all activities, and assess impacts of productivity changes on a schedule in order to establish a real-time schedule.

2.1 Methods

Every contractor utilizes some methodology to calculate its productivity. Such methods include:

- Measured Mile Analysis [22]
- Industry Organization Sources:
 - o Mechanical Contractors Association of America (MCAA) cost manual
 - o Individual Studies Sponsored by the Construction Industry Institute
 - o U.S. Army Corps of Engineers Modification Impact Guide
 - o The Business Roundtables Measuring Productivity in Construction
 - o The Associated General Contractors of America's National Joint Guidelines
 - o The National Electrical Contractors Association's Manual for Labor Units
 - o Electronics Industry Cost Estimating Data Booklet
 - o The Means Estimating Guide

- o Richardson's International Construction Factors Manual
- o Walker's Buildings Estimator's Reference Book
- Academic Research:
 - o Charles' Leonard's thesis on the effects of change orders on productivity

Rowings and Sonmez (1996) developed multivariate productivity models utilizing regression analysis and neural networks to simulate concrete pouring [3, 116]. Mao (1999) explored a method of using fuzzy set theory in estimation of labor productivity [89]. Griffis and Farr (2000) used heuristics (Historical Data), expert systems, statistical analysis, cycle-time analysis, queuing theory and simulation techniques to develop quantitative estimates of production rates for equipment-driven activities [15, 27, 52, and 64].

APBSA implements a stochastic simulation approach that focuses solely on the productivity of the driving resource, as opposed to considering any combination of or even all resources simultaneously. For example, in the case of formwork installation there are the productivity of the delivery resources and the productivity of the installation resources. Only one of the two will drive the duration and subsequently the cost.

2.2 Relationship between Productivity and Cost

If C_u is the unit cost of an activity, C_w represents the cost of that activity per week and N_t is its production in units per week, then

$$C_u = \frac{C_w}{N_t} \quad (2.2.1)$$

If C is the cost of an activity, Q is the quantity of that activity and N_c is the production rate based on cost, then

$$C = \frac{Q}{N_c} \quad (2.2.2)$$

or

$$C = C_u Q \quad (2.2.3)$$

and

$$C = C_w T \quad (2.2.4)$$

where T is the duration of the activity in weeks.

A cost-based productivity index, N_{fc} , is used to produce a comparable unit for all activities. N_{fc} is the fraction of the total activity completed each week over the fraction of the total cost of the activity used each week.

$$N_{fc} = \frac{Q_f}{C_f} \quad (2.2.5)$$

where Q_f is the fraction of the total activity completed each week (Weekly Completed Quantity, Q_w over Total Quantity, Q_t), and C_f is the fraction of the total cost of the activity used each week (Weekly Cost, C_w over Total Cost, C_t).

$$Q_f = \frac{Q_w}{Q_t} \quad (2.2.6)$$

and

$$C_f = \frac{C_w}{C_t} \quad (2.2.7)$$

Thus,

If $N_{fc} = 1$, then weekly productivity equals the baseline productivity.

If $0 < N_{fc} < 1$, then weekly productivity is less than the baseline productivity.

If $\infty > N_{fc} > 1$, then weekly productivity is more than the baseline productivity.

After N_{fc} values for each week are calculated, continuous probability distribution fits are selected based on their chi-squared statistic value ranking. For example, parameters for fitted BetaGeneral distribution based on weekly cost data for formwork installation (Figure 2.2.1, Appendix D.2) are:

$$\text{Alpha1} = 0.96912$$

$$\text{Alpha2} = 2.0900$$

$$\text{Minimum} = 0.0011984$$

$$\text{Maximum} = 2.3974$$

$$\text{Mean } N_{fc} = 0.76030$$

These parameters will be entered by the user as input values to define formwork installation activity probability distribution during APBSA simulation based on cost in Section 5.5.

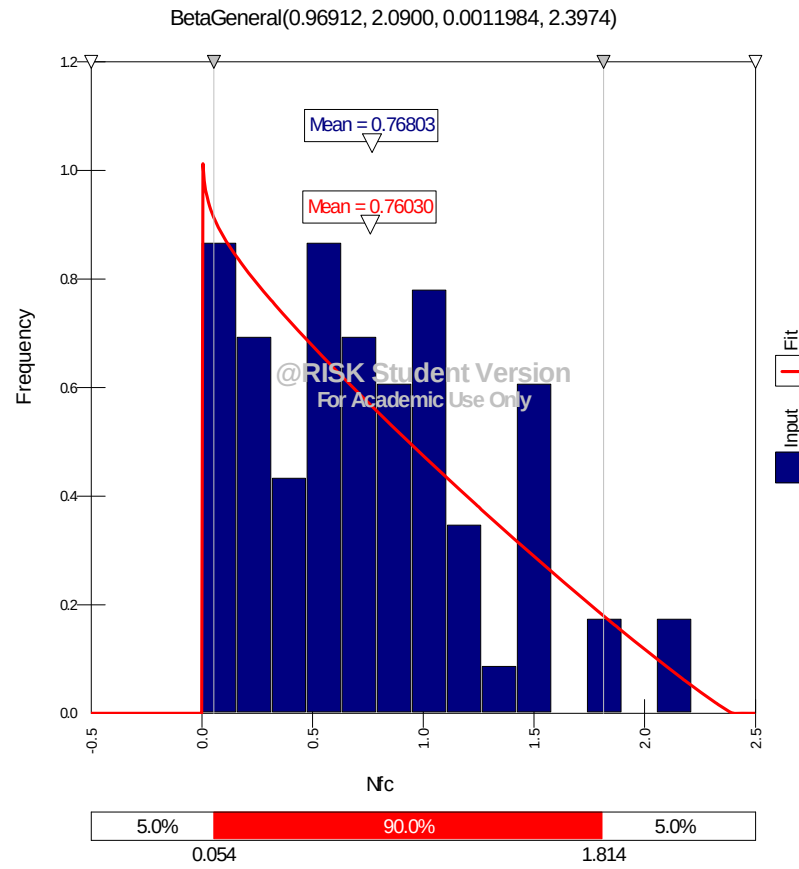


Figure 2.2.1 Install formwork fitted distribution based on weekly cost data

2.3 Relationship between Productivity and Duration

The relationship between productivity and duration of an activity is hyperbolic.

$$N_t = \frac{Q}{T} \quad (2.3.1)$$

where N_t is the production rate based on time, Q is the quantity of the activity, and T is the duration of the activity. Thus, the duration is halved when the production rate doubles.

Duration based productivity index, N_{ft} , is used to produce a comparable unit for all activities. N_{ft} , is the fraction of the total activity completed each week over the fraction of the total hours of the activity used each week.

$$N_{ft} = \frac{Q_f}{T_f} \quad (2.3.2)$$

where Q_f is the fraction of the total activity completed each week (Weekly Completed Quantity, Q_w over Total Quantity, Q_t), and T_f is the fraction of the total hours of the activity used each week (Weekly Man-hours, T_w over Total Man-Hours, T_t).

$$Q_f = \frac{Q_w}{Q_t} \quad (2.3.3)$$

and

$$T_f = \frac{T_w}{T_t} \quad (2.3.4)$$

Thus,

If $N_{ft} = 1$, then weekly productivity equals the baseline productivity.

If $0 < N_{ft} < 1$, then weekly productivity is less than the baseline productivity.

If $\infty > N_{ft} > 1$, then weekly productivity is more than the baseline productivity.

After N_{ft} values for each week are calculated, continuous probability distribution fits are selected based on their chi-squared statistic value ranking. For example, parameters for fitted Normal distribution based on weekly time data for formwork installation (Figure 2.3.1, Appendix D.3):

$$\text{Mean} = 0.84370$$

Standard Deviation = 0.57824

Mean $N_{ft} = 0.84370$

These parameters will be entered by the user as input values to define formwork installation activity probability distribution during APBSA simulation based on time in Section 5.6.

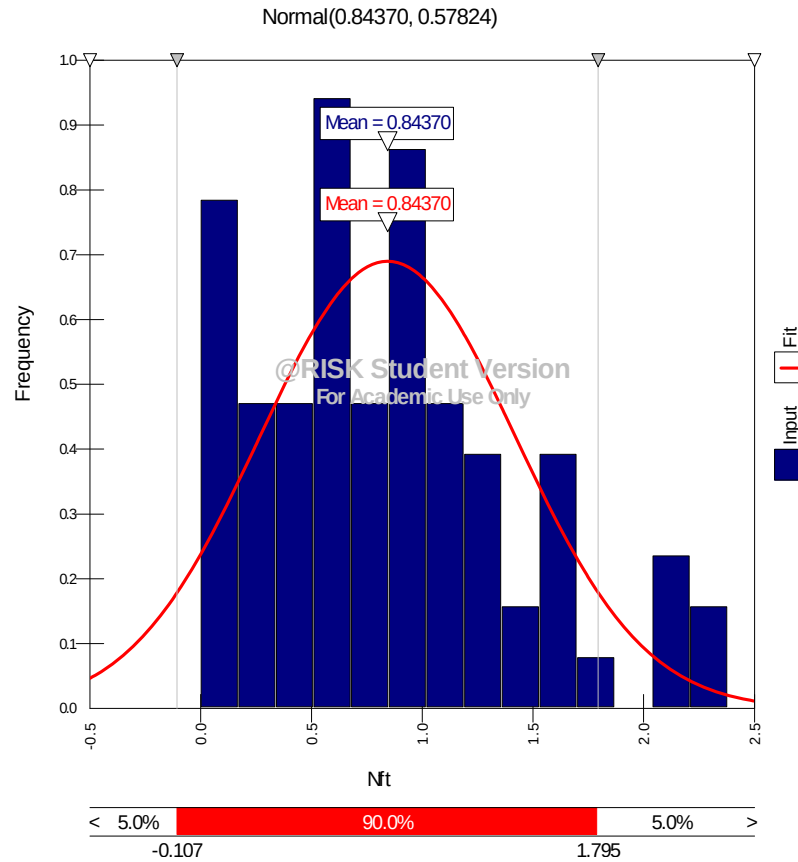


Figure 2.3.1 Install formwork fitted distribution based on weekly time data

2.4 Real-time Schedule

Real-time remaining duration of an activity can be calculated using the calculated real-time productivity values, N_{ft} or N_{fc} . Duration and productivity are inversely proportional.

$$N_{at} = \frac{Q_w}{T_w} \quad (2.4.1)$$

$$N_{bt} = \frac{Q_t}{T_t} \quad (2.4.2)$$

$$\frac{N_{bt}}{N_{at}} = \frac{Q_t}{T_t} \cdot \frac{T_w}{Q_w} = \frac{Q_t}{Q_w} \cdot \frac{T_w}{T_t} = \frac{T_p}{Q_p} = \frac{1}{N_{ft}} \quad (2.4.3)$$

$$\frac{D_{rt}}{(D_t - D_p)} = \frac{N_{bt}}{N_{at}} \quad (2.4.4)$$

$$D_{rt} = \frac{N_{bt}}{N_{at}} \cdot (D_t - D_p) = \frac{(D_t - D_p)}{N_{ft}} \quad (2.4.5)$$

$$D_{at} = D_p + D_{rt} = D_p + \frac{(D_t - D_p)}{N_{ft}} \quad (2.4.6)$$

where D_t is the total duration of the analyzed activity calculated at bid time, D_p is its passed duration since the Notice to Proceed (NTP), D_{rt} is its remaining duration based on time, D_{at} is its actual total duration based on time, N_{bt} is the production in units per week calculates at bid time, and N_{at} is the real-time actual production in units per week.

Thus,

If $D_t = D_{at}$, then weekly productivity equals to the baseline productivity.

If $D_t < D_{at}$, then weekly productivity is less than the baseline productivity.

If $D_t > D_{at}$, then weekly productivity is more than the baseline productivity.

or

$$N_{ac} = \frac{Q_w}{C_w} \quad (2.4.7)$$

$$N_{bc} = \frac{Q_t}{C_t} \quad (2.4.8)$$

$$\frac{N_{bc}}{N_{ac}} = \frac{Q_t}{C_t} \cdot \frac{C_w}{Q_w} = \frac{Q_t}{Q_w} \cdot \frac{C_w}{C_t} = \frac{C_p}{Q_p} = \frac{1}{N_{fc}} \quad (2.4.9)$$

$$\frac{N_{bc}}{N_{ac}} = \frac{Q_t}{C_t} \cdot \frac{C_w}{Q_w} = \frac{Q_t}{Q_w} \cdot \frac{C_w}{C_t} = \frac{Q_t}{Q_w} \cdot \frac{C_w}{C_w \cdot T} = \frac{Q_t}{Q_w} \cdot \frac{1}{T} \quad (2.4.10)$$

$$\frac{D_{rc}}{(D_t - D_p)} = \frac{N_{bc}}{N_{ac}} \quad (2.4.11)$$

$$D_{rc} = \frac{N_{bc}}{N_{ac}} \cdot (D_t - D_p) = \frac{(D_t - D_p)}{N_{fc}} \quad (2.4.12)$$

$$D_{ac} = D_p + D_{rc} = D_p + \frac{(D_t - D_p)}{N_{fc}} \quad (2.4.13)$$

where D_{rc} is its remaining duration based on cost, D_{ac} is its actual total duration based on cost, N_{bc} is the production in units per dollar calculated at bid time, and N_{ac} is the real-time actual production in units per dollar.

Thus,

If $D_t = D_{ac}$, then weekly productivity equals to the baseline productivity.

If $D_t < D_{ac}$, then weekly productivity is less than the baseline productivity.

If $D_t > D_{ac}$, then weekly productivity is more than the baseline productivity.

D_{at} and D_{ac} values will be used to update the schedule and illustrate the actual status of construction in relation to baseline schedule in Navisworks Manage (Bentley Navigator) animation as explained in Section 6.1.

CHAPTER 3: STATISTICAL ANALYSIS

Statistical analysis involves the sampling of data, the development of correlation matrices and determining best-fit distributions. Correlation matrices (Appendix C) and probabilistic distribution functions (Appendix D) of the activities described in Section 1.3 were developed in order to stochastically determine the impacts of each user-defined factor on the productivity indices of the activities. Additional material on statistical analysis can be found in Appendix B.

@RISK is a commercially available software program used to perform statistical analysis. @RISK can be used to analyze risk using Monte Carlo simulation to generate possible outcomes and how likely they are to occur [11].

3.1 Sampling

Sampling is a process by which values are randomly drawn from input probability distributions. It is done repetitively in a simulation, with one sample drawn every iteration from each input probability distribution. Sampled values for a probability distribution become distributed in a manner which approximates the known input probability distribution with a sufficient number of iterations. The statistics (mean, standard deviation and higher moments) of the sampled distribution approximate the true character of the input distribution. Even the graph of the sampled distribution will look like the graph of the true input distribution [11].

A sampling method is considered to be less "efficient" if it requires more iterations and longer simulation runtimes to approximate its input distribution. Monte

Carlo sampling often, particularly if the input distribution is highly skewed or has some outcomes of low probability, requires a large number of samples to approximate an input distribution. Latin Hypercube sampling, which is discussed in Section 3.3 converges faster on the true statistics of the input distribution since it forces the samples drawn to correspond more closely with the input distribution. It is a much more efficient option than Monte Carlo sampling since it also produces a more accurate estimate of the mean productivity index. It is recommended to use Latin Hypercube sampling type, unless the modeling condition specifically calls for Monte Carlo sampling [11].

3.2 Monte Carlo Sampling

Monte Carlo sampling is a technique that uses random or pseudo-random numbers to sample from a probability distribution. Monte Carlo sampling techniques are totally random since any given sample may fall anywhere within the range of the input distribution, but samples are more likely to be drawn in areas of the distribution which have higher probabilities of occurrence. In the cumulative distribution (Appendix B.2), each Monte Carlo sample uses a new random number between 0 and 1. Monte Carlo sampling "recreates" the input distributions through sampling with a sufficient number of iterations [11].

Clustering can occur when a small number of iterations are performed and the resulting distribution includes a disproportionate number of low probability outcomes. A small number of Monte Carlo iterations may not sample sufficient quantities of these outcomes to accurately represent their probability if their probability is low enough.

Stratified sampling techniques such as the Latin Hypercube sampling are developed to resolve this problem [11].

3.3 Latin Hypercube Sampling

Latin Hypercube sampling is a sampling technique designed to accurately recreate the input probability distributions specified by distribution functions through a fewer number of iterations than the Monte Carlo method. Stratification of the input probability distributions is the key to Latin Hypercube sampling. A cumulative curve (Appendix B.2) is divided into equal intervals on the cumulative probability scale (0.0 to 1.0) by stratification. "Sampling without replacement" technique is being used during Latin Hypercube sampling. The number of stratifications of the cumulative distribution is equal to the number of iterations performed. A sample is randomly taken from each interval or "stratification" of the input distribution. Once a sample is taken from a stratification, this stratification is not sampled from again since its value is already represented in the sampled set [11].

The samples more accurately reflect the distribution of values in the input probability distribution with Latin Hypercube compared to the clustered samples drawn using the Monte Carlo method [11].

3.4 Latin Hypercube and Low Probability Outcomes

The values sampled for one variable need to be independent of those sampled for another unless their correlation is explicitly wanted when using the Latin Hypercube technique to sample from multiple variables. Randomness and independence are

preserved; and unwanted correlations between variables are avoided by randomly selecting the interval to draw a sample from for each variable. In a given iteration, Variable #1 may be sampled from stratification #3, Variable #2 may be sampled from stratification 16, and so on [11].

Latin Hypercube offers great benefits in terms of increased sampling efficiency and faster runtimes due to less number of iterations especially in a PC based simulation environment such as @RISK. Latin Hypercube sampling assures low probability outcomes are accurately represented in input probability distributions and in simulation outputs by forcing the sampling of the simulation to include the outlying events [11].

It often helps to run an analysis which just simulates the contribution to the output distribution only from the low probability events (they are set to 100% probability) when low probability outcomes are very important. This way those outcomes will be isolated and the results they generate will be studied directly [11].

3.5 Correlation Matrix

Correlation refers to the strength, noisiness and direction of a linear relationship between two random variables and the departure of those variables from independence.

The correlation matrix of n random variables $X_1, \dots, X_n$ is the $n \times n$ matrix with a $\text{corr}(X_i, X_j)$ i, j entry. The correlation matrix is the same as the covariance matrix (Appendix B.1) of the standardized random variables $X_i / SD(X_i)$ for $i = 1, \dots, n$ if the measures of correlation used are product-moment coefficients. Consequently, it is a positive-semidefinite matrix. Correlation matrices of factors and activities described in

Section 1.3 can be found in Appendix C. The correlation matrix is symmetric since the correlation between X_i and X_j is the same as the correlation between X_j and X_i .

A Hermitian matrix (self-adjoint matrix) is a square matrix with complex entries which is equal to its own conjugate transpose. The element in the i^{th} row and j^{th} column is equal to the complex conjugate of the element in the j^{th} row and i^{th} column, for all indices i and j :

$$a_{i,j} = \overline{a_{j,i}} \quad (3.5.1)$$

The $n \times n$ Hermitian matrix M is called positive-semidefinite (nonnegative-definite) if $x^* M x \geq 0$ for all $x \in C^n$ (or, all $x \in R^n$ for the real matrix).

Where C^n and R^n are the n -dimensional complex and real vector spaces and x^* denotes the conjugate transpose of x .

A matrix M is positive-semidefinite if and only if it arises as the Gram matrix for some set of vectors. These vectors need not be linearly independent in contrast to the positive-definite case.

A Gram (Gramian) matrix of a set of vectors $v_1, \dots, v_n$ in an inner product space is the symmetric matrix of inner products, whose entries are given by $G_{ij} = (v_i, v_j)$. A set of vectors is linearly independent if and only if the determinant of the Gram matrix is non-zero.

For any matrix M , the matrix $M^* M$ is positive semidefinite, and $\text{rank}(M) = \text{rank}(M^* M)$. Conversely, any positive semidefinite matrix N can be written as $N = M^* M$; where M^* denotes the conjugate transpose of M . This is the Cholesky decomposition which is commonly used in the Monte Carlo method for simulating

systems with multiple correlated variables. The matrix of inter-variable correlations is decomposed to give the lower-triangular L . Applying this to a vector of uncorrelated samples, u , produces a sample vector L_u with the covariance properties of the system being modeled. This correlation allows a relationship to be specified among the values sampled in different worksheet cells while still maintaining a degree of uncertainty for each. It is important to recognize correlations in sampling when using sampled, uncertain variables in worksheet models. All uncertain variables will be sampled as if they were completely independent of other variables in the model if correlation is not used. It is very important to correctly recognize correlations between variables or the model might generate irrational results [11].

3.6 Fitted Distributions

Continuous probability distribution fits were ranked by their chi-squared (Appendices B.6, B.7) statistic values; and fitted distributions (Appendix B.4) were selected (Highlighted with yellow in Appendices D.4, D.5) based on the number of invalid fits in 7 consecutive runs, since productivity data is continuous sample data (Appendix B.5). Data values less than zero were filtered in the first run since they meant adjustments that were made to lower down the over reported quantities of an activity (Figure 3.6.1).

Beta (Generalized), Exponential, Inverse Gaussian, Logistic, Loglogistic, and Lognorm are the fitted distributions that were decided on the selected activities based on cost (Table 3.6.1). Beta (Generalized), Exponential, Extreme Value, Inverse Gaussian,

LogLogistic, Lognorm, Normal, Pearson Type V, and Triangular are the fitted distributions that were decided on the selected activities based on time (Table 3.6.2).

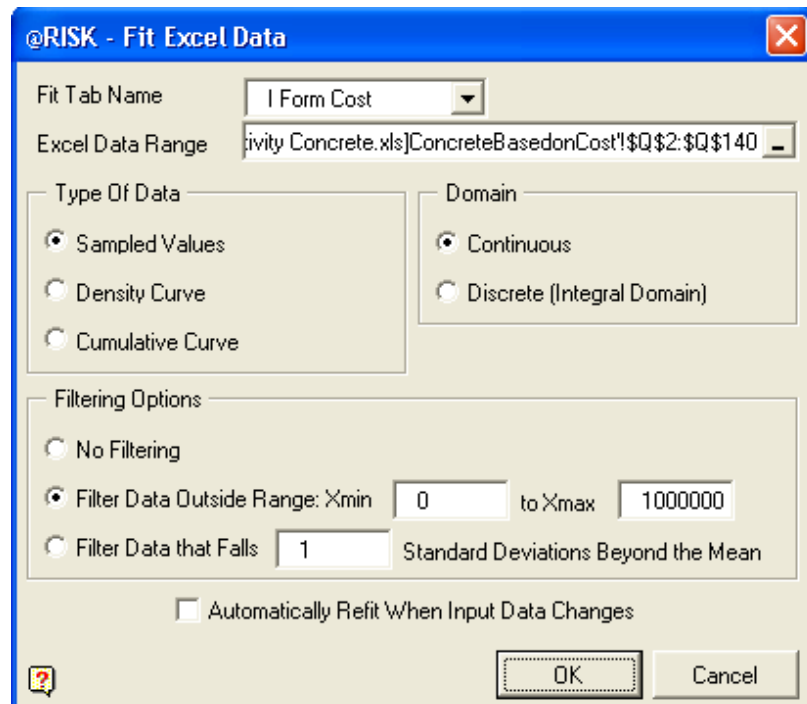


Figure 3.6.1 @Risk Fit Distributions to Excel Data

Activity	Fitted Distribution Based on Cost	Alpha	Beta	Gamma	Alpha1	Alpha2	Lambda	Min	Max	Mean	Mu	Standard Deviation
Furnish Concrete	Expon		0.21									
Install Formwork	BetaGeneral				0.97	2.09		0.00	2.40			
Install Rebar	Lognorm									0.54		0.58
Pour Concrete	LogLogistic	1.38	2.40	0.00								
Finish Concrete	BetaGeneral				0.70	3.16		0.01	2.31			
Furnish & Install Grout	InvGauss						0.95				0.45	
Excavation	Logistic	0.29	0.14									
Place Fills	Logistic	2.48	1.15									
Change Orders	Expon		0.11									
Unit Prices	Expon		0.16									
Cut-Off, Haul & Dispose Piles	InvGauss						1.50				1.26	
Demolition	Lognorm									27.82		793.00
Structural Steel	BetaGeneral				0.19	0.20		0.05	2.52			
Miscellaneous Metal	InvGauss						0.54				3.06	
Mechanical	BetaGeneral				0.43	2.09		0.01	39.76			
Furnish & Install Pipes & Fittings	InvGauss						0.25				0.47	
Thermal & Moist Protection	BetaGeneral				0.66	0.73		1.16	23.25			
Doors & Windows	Lognorm									0.37		1.48

Table 3.6.1 Fitted Distributions and Variables Based on Cost

Activity	Fitted Distribution Based on Time	Alpha	Beta	Gamma	Alpha1	Alpha2	Lambda	Min	Max	Mean	Mu	Standard Deviation	Most Likely
Furnish Concrete	BetaGeneral				0.19	0.20		0.00	0.18				
Install Formwork	Normal									0.84		0.58	
Install Rebar	LogLogistic	1.85	0.40	-0.01									
Pour Concrete	Pearson5	2.48	5.21										
Finish Concrete	Lognorm									0.66		1.30	
Furnish & Install Grout	InvGauss						0.90				0.71		
Excavation	BetaGeneral				0.58	1.58		0.03	1.49				
Place Fills	Normal									2.53		1.72	
Change Orders	Expon		0.77										
Unit Prices	BetaGeneral				0.88	17.04		0.02	2.93				
Cut-Off, Haul & Dispose Piles	LogLogistic	2.02	0.83	-0.08									
Demolition	Pearson5	0.48	0.20										
Structural Steel	ExtValue	3.06	1.58										
Miscellaneous Metal	Pearson5	1.28	0.85										
Mechanical	Lognorm									14.20		87.45	
Furnish & Install Pipes & Fittings	InvGauss						0.35				0.54		
Thermal & Moist Protection	Triang							0.32	23.99				8.51
Doors & Windows	Expon		0.89										

Table 3.6.2 Fitted Distributions and Variables Based on Time

CHAPTER 4: AUTOMATED PRODUCTIVITY BASED SCHEDULE ANIMATION (APBSA)

4.1 Research Objectives

Every construction company has its own way of quantity reporting, trending construction activities and keeping their historical data. In such systems, anticipated quantities are reported by estimators; weekly reported actual quantities are reported by field engineers and labor hours are entered by time keepers. Utilizing these data labor productivity rates and cost to complete values for the trended activities are produced.

APBSA v1.0 imports the construction labor productivity data (Factor and Weight) of the trended activities from the labor productivity trending database. These input values can also be entered manually. “Factor Weight” values are obtained by utilizing the regression analysis or expert systems (user defined factors) as shown in Figure 4.1.1.

	Factor	Weight	Percent Change	Product
▶	Bonus	2	1.00	2.00
	Change Order	2	1.00	2.00
	Constructability	2	0.00	0.00
	Culture	1	-1.00	-1.00
	Duration	2	0.00	0.00
	Equipment Availa...	3	-1.00	-3.00
	Location	3	1.00	3.00

Figure 4.1.1 Productivity Analysis Algorithm Interface

APBSA v1.0 Productivity Analysis Algorithm “Percent Change” values ($-1 \leq \text{Percent Change} \leq 1$) represent changes in factors with respect to their baseline values and entered manually. “Product” is the “Factor Weight” times the “Percent Change”, and “Productivity Ratio” (Real-time Productivity / Baseline Productivity) is the sum of Products.

APBSA v1.0 results were not satisfying since the regression analysis factors were not fully independent of each other. So, we decided to develop APBSA v2.0 which uses stochastic simulation approach to determine the effects of factors on the productivity.

APBSA v2.0 selection screen asks you to choose a project and a task, productivity estimation basis and finally a related activity (Figure 4.1.2).

Figure 4.1.2 APBSA Simulation Based on Time Construction Activity Selection Screen

APBSA v2.0 run screen asks you to enter continuous probability distribution parameters (default Alpha, Beta, Gamma, A1, a2, Lambda, Min, Max, Mean, Mu, Standard Deviation, and Most Likely values are mean N_{ft} or N_{fc} values, Table 4.1.1 & Appendix D.1), and average weather data (Table 1.4.3). APBSA v2.0 run screen also

asks you to enter the number of distributions and iterations of simulation, bid and passed durations (Figure 4.1.3).

Activity	Mean Nft	Mean Nfc
Office Supervision	0.43	0.33
Field Supervision	0.26	0.29
Carpenter Foreman	0.20	0.22
Master Mechanic - Maintenance Foreman	0.83	0.74
Fuel, Oil, Grease for Equipment	0.27	0.27
Labor Shop Steward	0.97	1.07
Teamsters	1.14	1.17
Offsite Yard Crew	1.20	1.11
Survey Party	0.67	0.67
Maintain Field Office	1.79	0.67
Maintenance and Protection of Traffic (MPT)	0.96	0.97
Temp Access & Maintenance	0.64	0.20
Crane Support	0.27	0.57

Table 4.1.1 Mean N_{pt} and N_{pc} Values

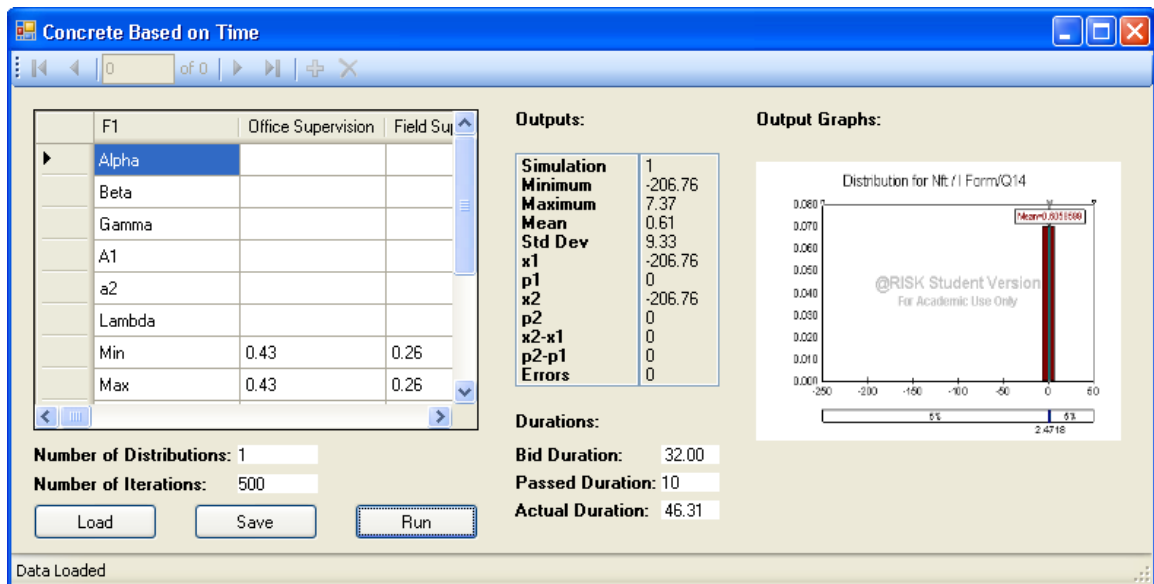


Figure 4.1.3 APBSA Simulation Based on Time Results Screen

After APBSA v2.0 calculates the actual durations for each of these construction activities, this output is fed to Navisworks Manage or Bentley Navigator in order to animate the actual progress of the job with most current data available (Figure 4.1.4).

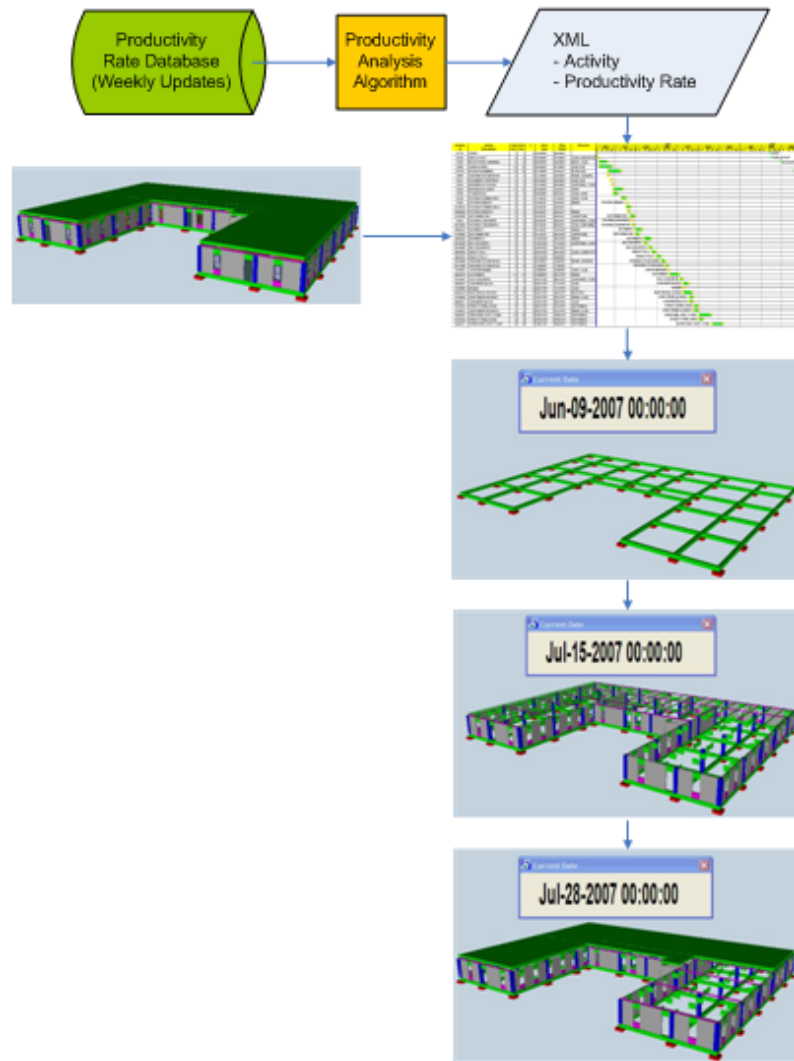


Figure 4.1.4 Automated Productivity Based Schedule Animation Processes

In summary, Automated Productivity Based Schedule Animation Flowchart (Figure 4.1.5) illustrates that APBSA

- Utilizes weekly trended productivity data;
- Uses stochastic simulation approach to determine the impact of user defined factors on labor productivity rates;
- Calculates new activity durations;
- Automatically updates the baseline schedule;

Finally, management team analyzes the simulation outputs, which are status report (Appendix E) and superimposed schedule animation (Figure 6.1.1), to understand the status of the project schedule. The team will identify delays if there are any and take necessary steps to eliminate obstacles or recognize and support the productive work in case of an early finish scenario. Decisions made by the management team affect labor productivities of the upcoming weeks that will be tracked and simulated to see the validity of the decisions and necessary adjustments will be made if needed.

Research objectives were presented to a research team on November 27, 2007 at Bentley Systems, Incorporated world headquarters in Exton, Pennsylvania and the possibility of the practical application of APBSA was confirmed.

CHAPTER 5: CASE STUDY

A three-dimensional model of the Systems Engineering Facility III (SMEFIII) at the Hanscom Air Force Base (AFB) in Bedford, MA was prepared to demonstrate the impacts of time and cost-based stochastic productivity indices on the baseline schedule and a time-cost trade-off (TCT) analysis is implemented to determine the optimum project duration that results in the minimum project total cost. SMEFIII is a three-story building that was constructed in 1986. Engineer's estimate was approximately ten million dollars in January 1986. The estimate to construct the same building today is about twenty million dollars.

Location of the building was crucial because special requirements for site access, material deliveries and work hours would affect the labor productivity. It is located next to Laurence G Hanscom Field which is a regional airport, sharing some facilities with the AFB. Geographically, it is close to the towns of Lincoln, Bedford, Concord, and Lexington, world-renowned for their rich colonial history. It is close to Routes 95/128 and about twenty miles northwest of Boston, "America's Technology Region." Minute Man National Historic Park, which is the early Revolutionary War battle site and origin of Paul Revere's famous ride and eventual capture, is on its south side (Figure 5.1).

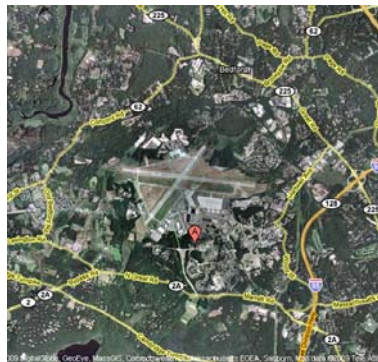


Figure 5.1 Location of Systems Engineering Facility III (SMEFIII)

5.1 Construction Baseline Schedule

Total duration of the SMEFIII aggressive construction baseline schedule was 254 work days, or 365 calendar days (Figure 5.1.1). Construction work was assumed to start on September 9, 2009 and finish on August 31, 2010 in this study.

Construction was planned to continue in four sectors simultaneously at each floor when needed in order to fully utilize crane operations. Mobilization, Approval/Procurement/Delivery of Steel, Erection of Structural Steel in Sector 1, Starting Exterior Masonry, Finishing Exterior Masonry, Fireproofing in Sector 1, Preparing Deck in Sector 1, Pouring Deck in Sector 1, Rough HVAC, Finish HVAC, Painting, Carpet Installation, and Demountable Glass Installation were the activities on the critical path. Critical path activities are highlighted with red in Tables 5.1.1 thru 5.1.3.

Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
SMEFIII Systems Management Engineering Facility III		254	254	1-Sep-09	31-Aug-10
SMEFIII General Conditions (New WBS)		250	250	1-Sep-09	25-Aug-10
A1000	Mobilize	5	5	1-Sep-09	8-Sep-09
A1910	General Conditions	245	245	9-Sep-09	25-Aug-10
SMEFIII HVAC (New WBS)-3		89	89	12-Mar-10	16-Jul-10
A1800	Rough HVAC 1	29	29	12-Mar-10	21-Apr-10
A1810	Rough HVAC 2	29	29	12-Mar-10	21-Apr-10
A1820	Rough HVAC 3	29	29	12-Mar-10	21-Apr-10
A1830	Rough HVAC 4	29	29	12-Mar-10	21-Apr-10
A1840	Finish HVAC	60	60	22-Apr-10	16-Jul-10
SMEFIII Electrical (New WBS)-2		62	62	8-Feb-10	4-May-10
A1750	Rough Electrical 1	7	7	8-Feb-10	16-Feb-10
A1760	Rough Electrical 2	7	7	8-Feb-10	16-Feb-10
A1770	Rough Electrical 3	7	7	8-Feb-10	16-Feb-10
A1780	Rough Electrical 4	7	7	8-Feb-10	16-Feb-10
A1790	Finish Electrical	40	40	17-Feb-10	13-Apr-10
A1850	Electrical Trim out	15	15	14-Apr-10	4-May-10

Table 5.1.1 Systems Management Engineering Facility III (SMEFIII) Construction Baseline Schedule of General Conditions, HVAC, and Electrical Activities

Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
SMEFIII.Plumbing (New WBS)-1		30	30	14-Sep-09	23-Oct-09
A1720	Install Sanitary/Steam/Water Lines	18	18	14-Sep-09	7-Oct-09
A1730	Site Drainage	12	12	8-Oct-09	23-Oct-09
SMEFIII.Architectural (New WBS)-6		175	175	24-Dec-09	31-Aug-10
A1340	Start Exterior Masonry	29	29	24-Dec-09	4-Feb-10
A1360	Start Interior Masonry	14	14	24-Dec-09	14-Jan-10
A1370	Finish Interior Masonry	11	11	15-Jan-10	29-Jan-10
A1390	Install Studs 1	5	5	1-Feb-10	5-Feb-10
A1400	Install Studs 2	5	5	1-Feb-10	5-Feb-10
A1410	Install Studs 3	5	5	1-Feb-10	5-Feb-10
A1420	Install Studs 4	5	5	1-Feb-10	5-Feb-10
A1350	Finish Exterior Masonry	25	25	5-Feb-10	11-Mar-10
A1430	Drywall 1	6	6	22-Apr-10	29-Apr-10
A1440	Drywall 2	6	6	22-Apr-10	29-Apr-10
A1450	Drywall 3	6	6	22-Apr-10	29-Apr-10
A1460	Drywall 4	6	6	22-Apr-10	29-Apr-10
A1470	Windows 1	24	24	30-Apr-10	3-Jun-10
A1480	Windows 2	24	24	30-Apr-10	3-Jun-10
A1490	Windows 3	24	24	30-Apr-10	3-Jun-10
A1500	Windows 4	24	24	30-Apr-10	3-Jun-10
A1550	Install Ceiling Sheetrock 1	9	9	30-Apr-10	12-May-10
A1560	Install Ceiling Sheetrock 2	9	9	30-Apr-10	12-May-10
A1570	Install Ceiling Sheetrock 3	9	9	30-Apr-10	12-May-10
A1580	Install Ceiling Sheetrock 4	9	9	30-Apr-10	12-May-10
A1590	Install Interim Door Frames	15	15	30-Apr-10	20-May-10
A1610	Install Hand Tiles	13	13	13-May-10	1-Jun-10
A1600	Hang Interim Doors	12	12	21-May-10	8-Jun-10
A1620	Finish Bathrooms	10	10	2-Jun-10	15-Jun-10
A1510	Glass Glazing 1	15	15	4-Jun-10	24-Jun-10
A1520	Glass Glazing 2	15	15	4-Jun-10	24-Jun-10
A1530	Glass Glazing 3	15	15	4-Jun-10	24-Jun-10
A1540	Glass Glazing 4	15	15	4-Jun-10	24-Jun-10
A1710	Paint	12	12	19-Jul-10	3-Aug-10
A1630	Install Carpet 1	11	11	4-Aug-10	18-Aug-10
A1640	Install Carpet 2	11	11	4-Aug-10	18-Aug-10
A1650	Install Carpet 3	11	11	4-Aug-10	18-Aug-10
A1660	Install Carpet 4	11	11	4-Aug-10	18-Aug-10
A1670	Demountable Glass 1	9	9	19-Aug-10	31-Aug-10
A1680	Demountable Glass 2	9	9	19-Aug-10	31-Aug-10
A1690	Demountable Glass 3	9	9	19-Aug-10	31-Aug-10
A1700	Demountable Glass 4	9	9	19-Aug-10	31-Aug-10

Table 5.1.2 Systems Management Engineering Facility III (SMEFIII) Construction Baseline Schedule of Plumbing and Architectural Activities

Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
SMEFIII.Civil (New WBS)-5		150	150	9-Sep-09	12-Apr-10
A1010	Retaining Wall	5	5	9-Sep-09	15-Sep-09
A1040	Site Layout	3	3	9-Sep-09	11-Sep-09
A1060	Pile Shop Drawings	5	5	9-Sep-09	15-Sep-09
A1050	Demolition (Sewer Line)	12	12	14-Sep-09	29-Sep-09
A1020	Transformer Wall & Pad	10	10	16-Sep-09	29-Sep-09
A1070	Approve/Procure/Deliver/Relocate Piles	5	5	16-Sep-09	22-Sep-09
A1030	Install Ramp	32	32	30-Sep-09	12-Nov-09
A1080	Test Piles	11	11	30-Sep-09	14-Oct-09
A1090	Piles 1&2	18	18	15-Oct-09	9-Nov-09
A1890	Piles 3&4	18	18	15-Oct-09	9-Nov-09
A1100	Pile Caps 1&2	4	4	10-Nov-09	13-Nov-09
A1110	Excavation	19	19	10-Nov-09	8-Dec-09
A1900	Pile Caps 3&4	4	4	10-Nov-09	13-Nov-09
A1130	Interior Grade Beam	4	4	9-Dec-09	14-Dec-09
A1140	Start Prep SOG All Trades	12	12	9-Dec-09	24-Dec-09
A1120	Exterior Grade Beam	5	5	15-Dec-09	21-Dec-09
A1150	Complete Prep SOG	10	10	28-Dec-09	11-Jan-10
A1160	Pour SOG	5	5	12-Jan-10	18-Jan-10
A1740	Site Pavements/Sidewalks/Curbs	60	60	19-Jan-10	12-Apr-10
SMEFIII.Structural (New WBS)-4		133	133	9-Sep-09	18-Mar-10
A1170	Approve/Procure/Deliver Steel	45	45	9-Sep-09	10-Nov-09
A1180	SS 1	15	15	11-Nov-09	3-Dec-09
A1200	SS 2	15	15	11-Nov-09	3-Dec-09
A1190	Fireproof 1	5	5	4-Dec-09	10-Dec-09
A1210	Fireproof 2	5	5	4-Dec-09	10-Dec-09
A1220	Prep Deck 1	4	4	11-Dec-09	16-Dec-09
A1230	Prep Deck 2	4	4	11-Dec-09	16-Dec-09
A1240	Pour Deck 1	5	5	17-Dec-09	23-Dec-09
A1250	Pour Deck 2	5	5	17-Dec-09	23-Dec-09
A1260	SS 3	15	15	24-Dec-09	15-Jan-10
A1280	SS 4	15	15	24-Dec-09	15-Jan-10
A1270	Fireproof 3	5	5	18-Jan-10	22-Jan-10
A1290	Fireproof 4	5	5	18-Jan-10	22-Jan-10
A1380	Concrete Encased Steel	16	16	18-Jan-10	8-Feb-10
A1300	Prep Deck 3	4	4	25-Jan-10	28-Jan-10
A1310	Prep Deck 4	4	4	25-Jan-10	28-Jan-10
A1320	Pour Deck 3	5	5	29-Jan-10	4-Feb-10
A1330	Pour Deck 4	5	5	29-Jan-10	4-Feb-10
A1860	Elevator Pit Rough Out	4	4	29-Jan-10	3-Feb-10
A1870	Install Elevator	30	30	4-Feb-10	17-Mar-10
A1880	Install Roofing	30	30	5-Feb-10	18-Mar-10

Table 5.1.3 Systems Management Engineering Facility III (SMEFIII) Construction Baseline Schedule of Civil and Structural Activities

5.2 Three Dimensional Modeling with AutoCAD Revit Architecture and MEP

AutoCAD Revit Architecture and MEP Suites were used for modeling (Figures 5.2.1 and 5.2.2). Autodesk Revit Architecture software is a building information modeling software. Revit Architecture promotes rapid visualization of design options. Autodesk Revit MEP software is also a building information modeling software for mechanical, electrical, and plumbing (MEP) systems that provides purpose-built tools for building systems design and analysis. Modifications are coordinated more consistently across the model with parametric change management technology. The designer can choose from multiple auto-layout path suggestions to determine the best path for the design, or modify the auto-layouts and let Revit MEP create the appropriate ductwork and fittings automatically. The ability to change a schedule and automatically update the model is a key benefit of Revit Architecture and MEP [10].



Figure 5.2.1 Google Earth Plan View of 245 Vandenberg Dr, Lincoln, MA

Custom quantity schedules for foundation insulation, vapor barriers, slabs-on-grade, piles, pile caps, structural columns, walls, doors, handrails were easy to get from the model. Area of foundation insulation is 3,300 square feet and area of vapor barrier is 31,270 square feet. Volume of concrete is 1,160 cubic yards for slab on grade and 295 cubic yards for pile caps. There are three hundred and eighty one pipe piles which are 12,648 linear feet in total. There are nine W12x106, twenty seven W12x40, thirty W12x50, twenty seven W12x53, fifty two W12x65, thirty two W12x96, eighteen W14x82, ninety eight W16x77 and a total of two hundred and ninety two columns in the building. There are 3,355 square feet of curtain walls and 85,611 square feet of non-bearing walls. There are twenty seven doors on the first floor, thirty nine doors on the second floor, and thirty three doors on the third floor. There is 280 linear feet of handrail. Area of each floor is 30,540 square feet, which makes a total of 91,620 square feet. These quantities will be utilized in duration analysis algorithm of the APBSA v3.0 with current productivity rates in order to get the real-time schedule.

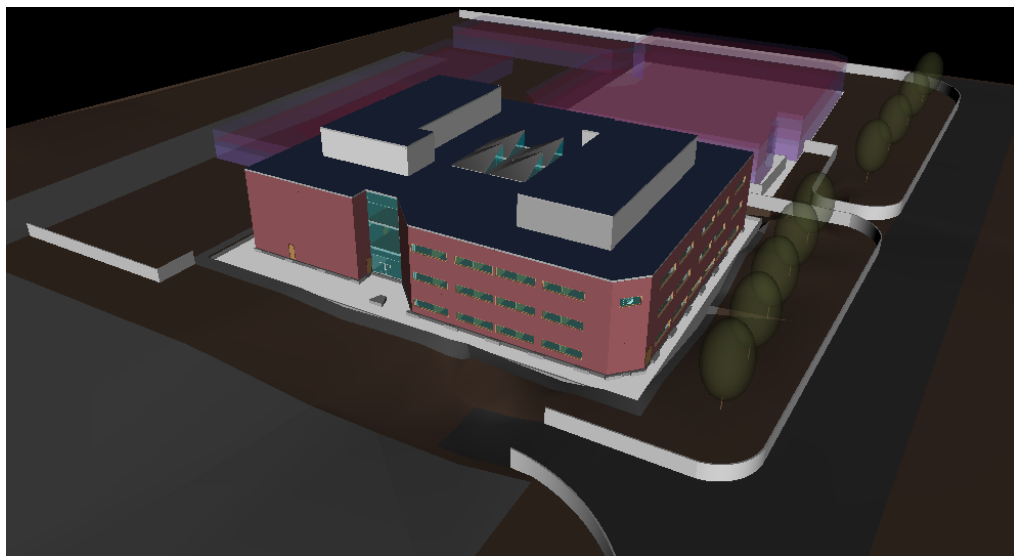


Figure 5.2.2 Revit Model of 245 Vandenberg Dr, Lincoln, MA

Three-dimensional modeling of simple topography and roads around the site took a week. Modeling and partitioning of exterior walls and roof also took a week. Modeling of HVAC items took 5 weeks and modeling of plumbing items took 4 weeks.

Level of detail of the model was limited to the major structural, architectural and HVAC elements. Modeling of structural steel connections, shear studs, steel bracing, rebar, electrical items, ventilation fans, boilers, transformers, and catch basins were omitted.

5.3 Background on Time-Cost Trade-off Analysis

Time-Cost Trade-off Problem (TCTP) is a major problem for complex and large-sized construction projects (Appendix F). A project may be behind schedule or the scheduled project deadline may have been moved forward. Crashing, which focuses on time-cost trade-offs, and fast tracking, which focuses on performing activities in parallel are two major schedule compression techniques.

Crashing, compressing, or time-cost trade-off analysis is a scheduling technique to reduce the original duration of critical path activities by allocating more resources to them or by changing their scope while maintaining quality requirements, to meet a specific deadline with the least incremental cost. The time required to complete a project is determined by the critical path, so to compress a project schedule, critical path activities with the lowest cost per unit of time reduction should be shortened first (e.g., Prep Deck 1). Costs of crashing activities include overtime premium, and more expensive resources.

Total project cost is the sum of the direct and indirect costs of performing the activities of the project. Direct costs for the project are directly associated with project activities, such as labor, material, equipment, and subcontractor costs. Indirect costs, on the other hand, are not directly associated with a particular activity or a specific project, such as marketing, bonds, insurance, taxes, interests, contractual penalties, overhead, and office space (rent and maintenance). Increasing pace of activities in order to decrease project duration will generally increase the project direct costs since more resources must be allocated to accelerate the pace. However, the indirect costs will decrease by decreasing the project duration, as they are relatively steady per unit of time over the life of the project forming almost a linear function with the project duration.

The minimum direct cost required to complete an activity is called the normal cost (minimum cost), and the corresponding duration is called the normal duration considering the activity is in isolation. At the other extreme, the shortest possible duration required to complete the activity is called the crash duration, and the corresponding cost is called the crash cost (maximum cost) [36].

5.4 SMEF III Time-Cost Trade-off Analysis

The SMEF III BIM was provided to twenty-five graduate students who were registered for the “Advanced Construction Systems Class.” The students were divided into five groups and each group prepared three schedules and corresponding bid proposals, each for a different construction duration (Site Work, Mobilize for Pile Work, Drive Test Piles (3 or 4), Pile Load Tests (3 or 4), Drive Steel Piles, and Building) using a building information model. The schedule for the first proposal was for 545 days, the

second proposal was for 455 days and the third was for 365 calendar days from the notice to proceed (NTP) date. Engineer's estimate in January 1986 was about 10 million dollars for 545 days schedule. Consumer Price Index for All Urban Consumers (CPI-U) was 109.6 in January 1986 and 216.33 in November 2009 [136]. The engineer's estimate was recalculated to be about 20 million dollars for November 2009 using an inflation of 97.38% since January 1986 for comparison purpose. The estimated increase in cost to perform the work in 455 calendar days and 365 calendar days, respectively, calculated by each group of students is shown in Table 5.4.1.

SMEF III	Site Work	Mobilize for Pile Work	Drive Test Piles (3 or 4)	Pile Load Tests (3 or 4)	Drive Steel Piles	Building	Total (545 days)	A (455 days)	B (365 days)
Engineer's Estimate (Jan 86)	\$ 404,220	\$ 16,000	\$ 1,800 \$ 600	\$28,800 \$ 9,600	\$ 240,312	\$ 9,538,384	\$10,229,516 \$10,239,716	\$ 990,000	\$1,400,000
Engineer's Estimate (Nov 09)	\$ 797,855	\$ 31,581	\$ 3,553 \$ 1,184	\$56,846 \$18,949	\$ 474,331	\$18,826,995	\$20,191,161 \$20,211,293	\$1,954,076	\$2,763,339
Group 1	\$5,608,000	\$ 55,000	\$ 9,750 \$ 3,250	\$ 4,500 \$ 1,125	\$1,204,980	\$ 9,935,000	\$16,817,230 \$16,821,605	\$1,809,517	\$2,035,983
Group 2	\$ 862,500	\$ 27,830	\$ 30,000 \$ 10,000	\$ 3,000 \$ 1,000	\$ 520,044	\$13,997,891	\$15,441,265 \$15,452,265	\$ 774,310	\$2,762,934
Group 3	\$5,788,582	\$ 17,500	\$ 90,000 \$ 30,000	\$30,000 \$10,000	\$ 373,549	\$12,119,928	\$18,419,559 \$18,459,559	\$1,626,051	\$3,177,371
Group 4	\$6,038,477	\$186,968	\$108,000 \$ 36,000	\$ 6,780 \$ 2,260	\$ 499,369	\$10,313,315	\$17,152,909 \$17,191,169	\$1,120,479	\$1,112,112
Group 5	\$1,322,809	\$ 22,000	\$ 92,400 \$ 30,800	\$ 9,240 \$ 3,080	\$ 589,153	\$29,594,239	\$31,629,841 \$31,663,721	\$1,515,875	\$2,176,559
Group Average	\$3,924,074	\$ 61,860	\$ 66,030 \$ 22,010	\$10,704 \$ 3,493	\$ 637,419	\$15,192,075	\$19,892,161 \$19,917,664	\$1,369,246	\$2,252,992

Table 5.4.1 SMEF III Construction Estimates for 545, 455 and 365 Calendar Day Schedules

The difference between the recalculated engineer's estimate (direct costs) and the group average was 1.48%, which is relatively small. Indirect costs of SMEF III project including rent was assumed to be \$450,000.00 per month and total costs were calculated by adding indirect costs to the engineer's estimate.

Days (t)	Direct Costs	Indirect Costs	Total Cost (c)
365	\$24,908,576	\$ 5,400,000	\$30,308,576
455	\$22,145,237	\$ 6,750,000	\$28,895,237
545	\$20,191,161	\$ 8,100,000	\$28,291,161

Table 5.4.2 SMEF III Direct, Indirect and Total Costs for Different Durations

A regression analysis was done on the SMEF III total construction cost estimate 365, 455 and 545 days values (Table 5.4.2, Appendix G). The regression equation was found to be

$$c = -11,207.86t + 34,264,568.14, t \geq 365 \text{ days} \quad (5.4.1)$$

where c is the cost in dollars and t is the duration of the project in days.

Reducing the duration of the project by 16.51% and 33.03% increases the total cost of the project by 2.14% and 7.13% relatively. On average overhead costs and profit each corresponds to 10% of the project's budget. Above study shows that profitability of a project can be increased by 20% or 70% by increasing labor productivity by 20% or 50% respectively.

The project time-cost relationship can be represented graphically by plotting project completion time against the direct, indirect and cumulative cost values together as shown in Figure 5.4.1. The optimum project duration can be determined as 545 days that results in the minimum project total cost.

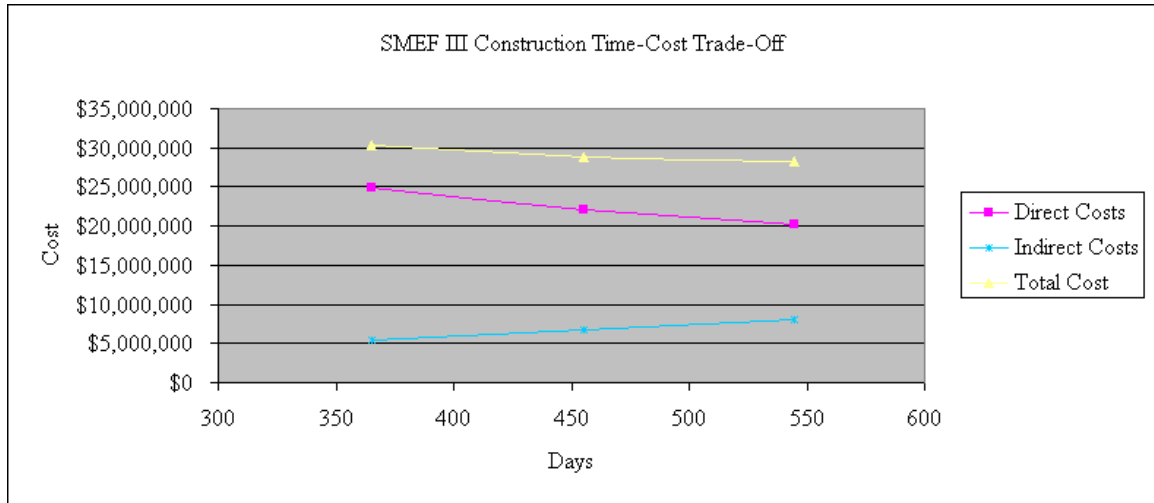


Figure 5.4.1 SMEF III Construction Time-Cost Trade-Off Relationship

In a scenario where the owner required the project to be completed on 365 days for the cost of 545 day schedule, on a micro level, by utilizing APBSA, SMEF III project management team could identify labor productivity related issues in the field and decide what needed to be done (like providing better supervision and/or equipment) in order to get productivity from $N_{545} = \frac{Q}{6}$ to $N_{455} = \frac{Q}{5}$ (20% increase) and finally to $N_{365} = \frac{Q}{4}$ (50% increase) where Q is the Prep Deck 1 quantity in square feet and N_{545} , N_{455} , N_{365} are relatively productivities for 545, 455 and 365 day schedules in square feet per day (Figure 5.4.2). On a macro level, APBSA could help the project management to understand the status of the project schedule, identify delays if there are any, take necessary steps to eliminate obstacles and boost craft productivity on the jobsite; or recognize and support the productive work in case of an early finish scenario; therefore increase profitability.

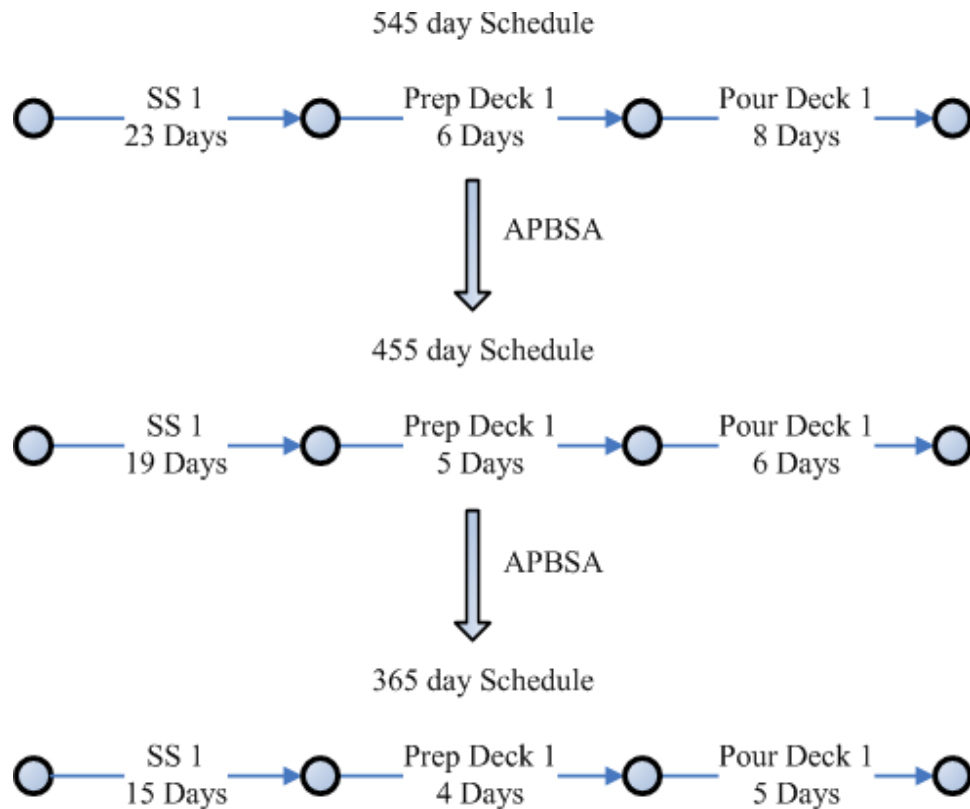


Figure 5.4.2 SMEF III Schedule Comparison

5.5 APBSA Simulation Based on Cost

Each iteration the spreadsheet is recalculated with a set of new possible values sampled from each input distribution, and new possible outcomes are generated when a risk analysis is run. The @RISK program keeps track of these output values as a simulation progresses and creates a distribution of possible outcomes by taking all the possible output values generated, analyzing them and calculating statistics on how they are distributed across the full range [11].

The number of iterations performed will affect the simulation execution time, quality and accuracy of the results. Run 100 (default value) iterations or less in order to get a quick look at results. Run 300 or 500 (or more) iterations for the most accurate

results. Convergence Monitoring (Appendix B.3) options can be used to run the amount of iterations required for accurate and stable results [11].

If the “Choose Randomly” option (Figure 5.5.1) is selected in the “Random Generator Seed” section of the Sampling tab of “Simulation Settings” prior to running multiple simulations, @RISK will randomly pick a new seed each simulation [11].

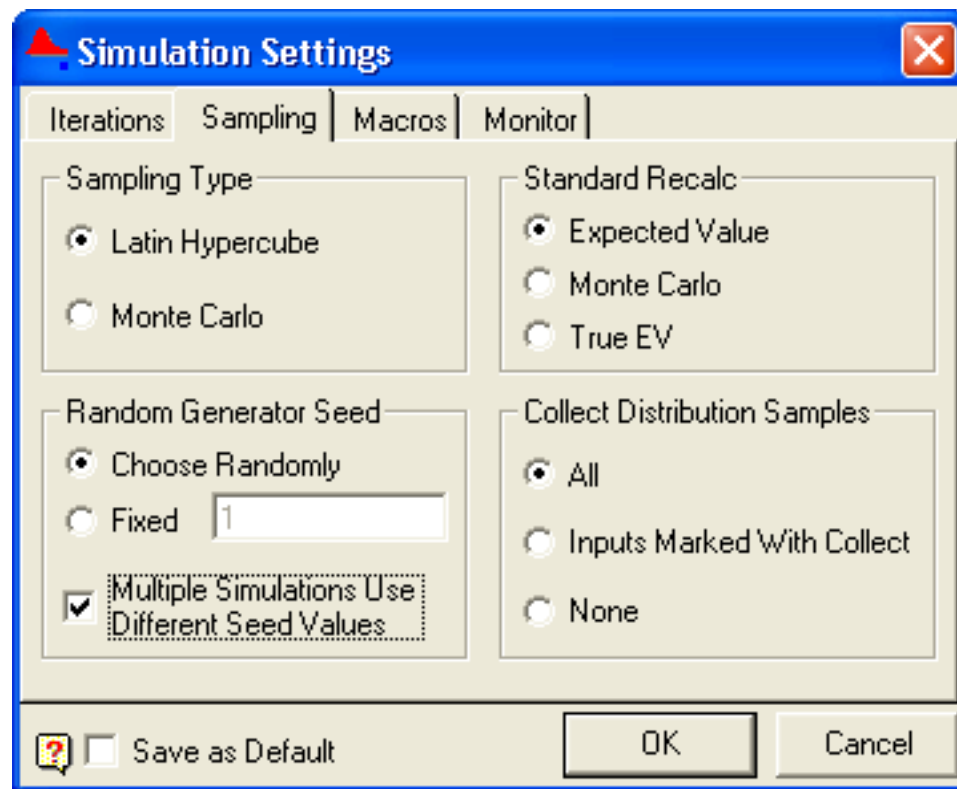


Figure 5.5.1 @Risk Simulation Settings

If “Fixed” seed option is selected, @RISK will use the same random number generator seed value for each executed simulation. The exact same sequence of random numbers will be repeated simulation to simulation when a fixed non-zero seed value (must be an integer in the range 1 to 2,147,483,647) is entered for the random number generator. The same random number will always return the same sampled value from a

given distribution function. Setting a fixed seed value is useful to control the simulation sampling environment. For example, the same model can be simulated twice by only changing the argument values for one distribution function. Differences in the results between the two runs will be directly caused by changing the argument values of the single distribution function since same values will be sampled each iteration from all distribution functions except the one that is changed by setting a fixed seed [11].

SIMTABLE specifies a list of values which will be used sequentially in individual simulations executed during a Sensitivity Simulation. If the “Multiple Simulations Use Different Seed Values” option is selected, the differences between simulations is not isolated to only the changes in the values returned by the SIMTABLE functions when the number of simulations is greater than 1 (default value). @RISK will use a different seed for each simulation in a multiple simulation run. If “Fixed” seed and “Multiple Simulations Use Different Seed Values” options are selected, each simulation will use a different seed, but the same sequence of seed values will be used each time the run is re-executed. Thus, results will be reproducible run to run [11].

In each iteration of each simulation [11]:

1. All distribution functions are sampled.
2. SIMTABLE functions return the argument corresponding to the number of the simulation being executed.
3. The worksheet is recalculated.
4. New calculated values in the cells of the selected output ranges are saved for use in creating output distributions.

Figures 5.5.2 thru 5.5.6 are screen shots of APBSA simulation based on cost for critical path activity “Prep Deck 1”.

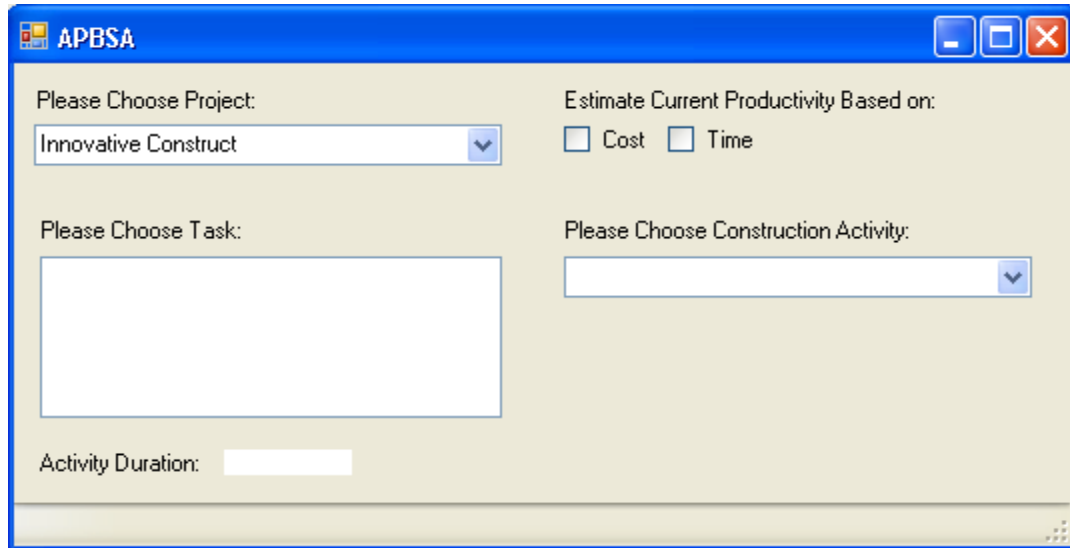


Figure 5.5.2 APBSA Startup Screen

Investigated project selection is made by the user in APBSA Project Selection Screen (Figure 5.5.3).

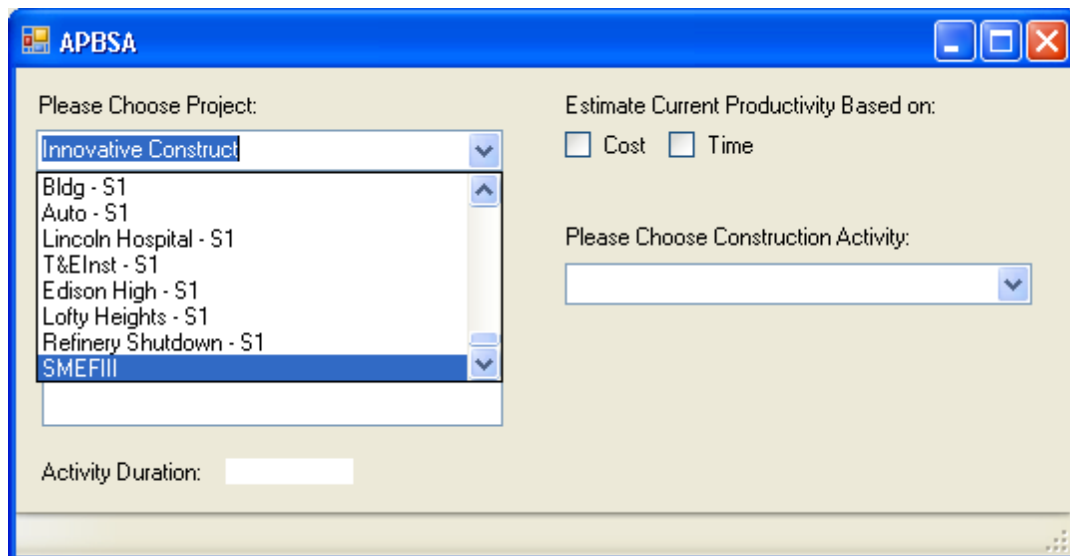
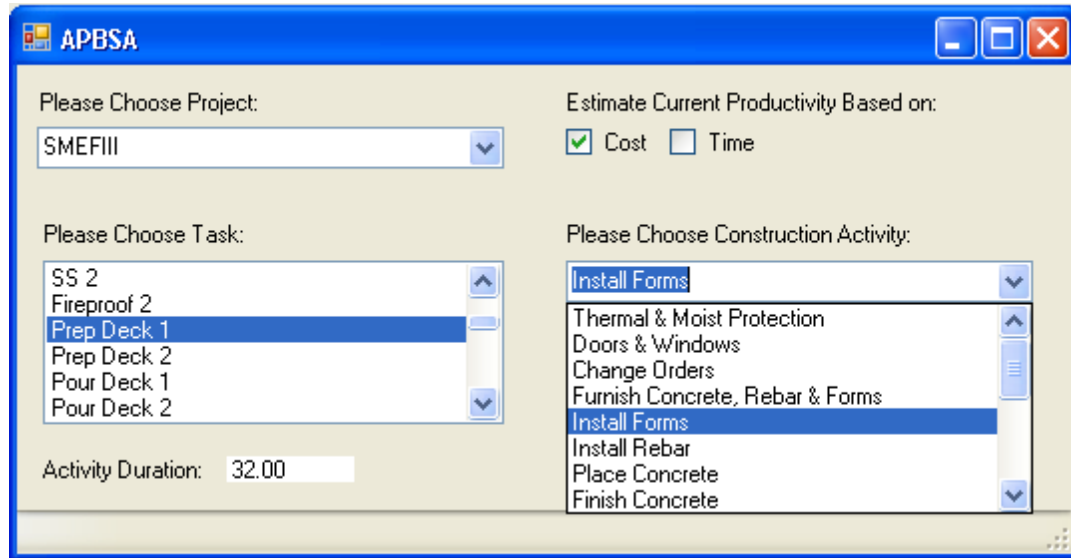


Figure 5.5.3 APBSA Project Selection Screen

Task selection, productivity basis selection as cost and construction activity selection are made by the user in APBSA Startup Screen after project selection screen (Figure 5.5.4).



The screenshot shows the APBSA software interface. At the top, the title bar reads 'APBSA'. Below it, there are four main sections:

- Please Choose Project:** A dropdown menu with 'SMEFIII' selected.
- Estimate Current Productivity Based on:** Two radio buttons, 'Cost' (checked) and 'Time' (unchecked).
- Please Choose Task:** A list box containing 'SS 2', 'Fireproof 2', 'Prep Deck 1' (highlighted), 'Prep Deck 2', 'Pour Deck 1', and 'Pour Deck 2'.
- Please Choose Construction Activity:** A list box containing 'Install Forms' (highlighted), 'Thermal & Moist Protection', 'Doors & Windows', 'Change Orders', 'Furnish Concrete, Rebar & Forms', 'Install Rebar', 'Place Concrete', and 'Finish Concrete'.

At the bottom left, there is a label 'Activity Duration:' followed by a text box containing '32.00'.

Figure 5.5.4 APBSA Simulation Based on Cost Task Selection Screen

Passed duration, number of distributions, and number of iterations, continuous probability distribution parameters (default Alpha, Beta, Gamma, A1, a2, Lambda, Min, Max, Mean, Mu, Standard Deviation, and Most Likely values are mean N_{fc} values, Table 4.1.1 & Appendix D.1), and average weather data (Table 1.4.3) are entered by the user in an APBSA simulation based on cost. In an APBSA demonstration simulation based on cost, five hundred iterations was run for a passed duration (D_p) of ten days for one distribution (Figure 5.5.5).

At the end of the above demonstration simulation based on cost, the fraction of the total activity “Prep Deck 1” completed each week over the fraction of the total cost of the activity used each week (N_{fc}) was found to be 0.94 (mean value), which means that

the current weekly actual unit cost of “Prep Deck 1” is more than what was given in the bid, and the weekly productivity is less than the baseline productivity (Figure 5.5.5). Consequently, the actual total duration based on cost (D_{ac}) of the activity was found to be 34 work hours (5 work days) compared to 32 work hours (4 work days) in the bid and as a result the remaining duration (D_{rc}) was 24 work hours (3 work days).

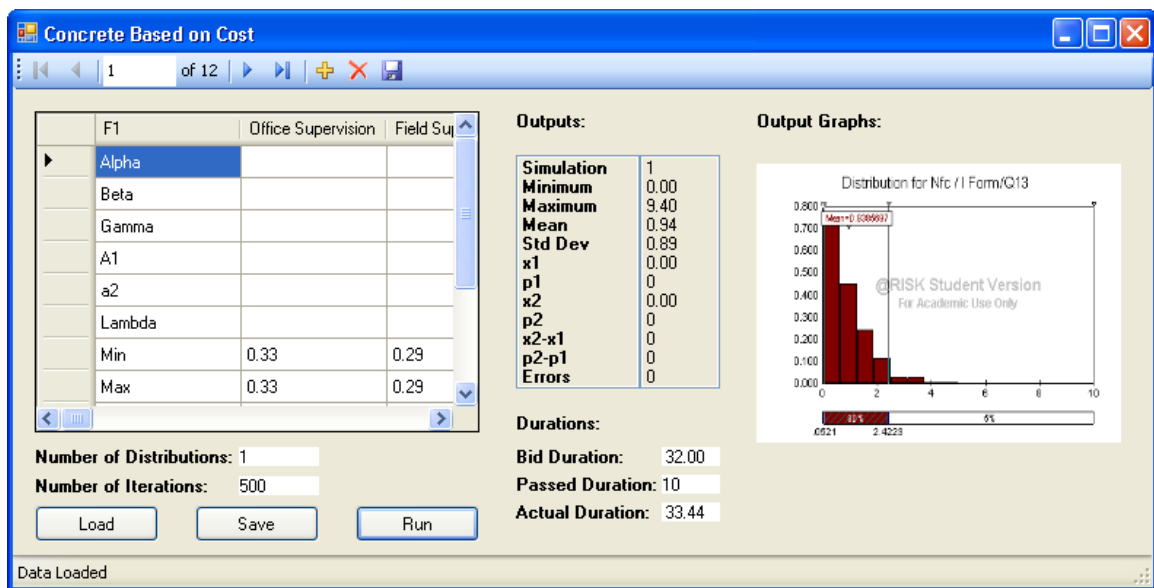


Figure 5.5.5 APBSA Simulation Based on Cost Results Screen

5.6 APBSA Simulation Based on Time

Figures 5.6.1 thru 5.6.3 are screen shots of an APBSA simulation based on time for the same critical path activity “Prep Deck 1”. Task selection, productivity basis selection as cost and construction activity selection are made by the user in APBSA Startup Screen after project selection screen (Figure 5.6.1).

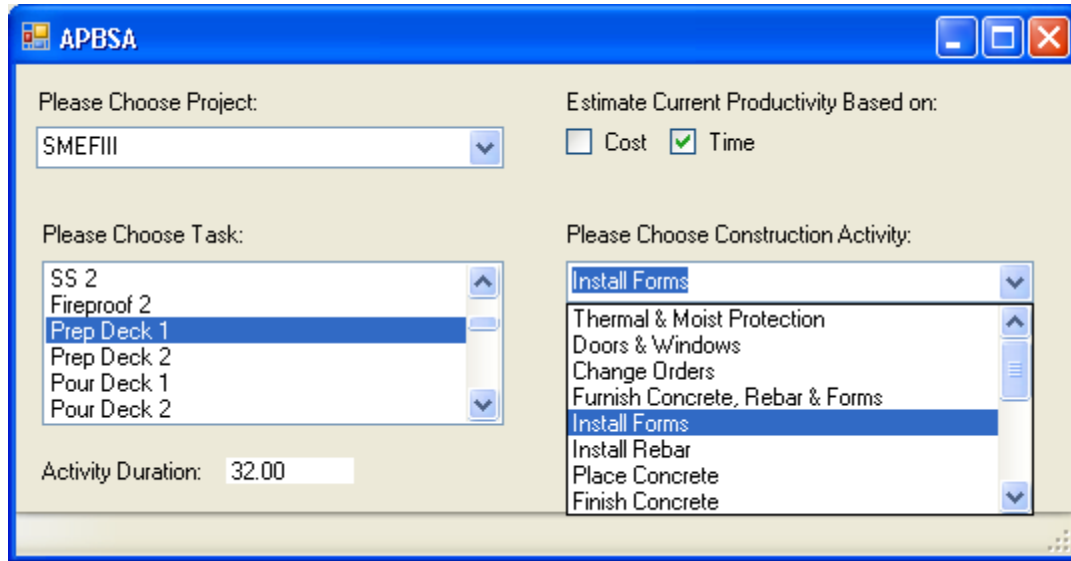


Figure 5.6.1 APBSA Simulation Based on Time Task Selection Screen

Passed duration, number of distributions, and number of iterations, continuous probability distribution parameters (default Alpha, Beta, Gamma, A1, a2, Lambda, Min, Max, Mean, Mu, Standard Deviation, and Most Likely values are mean N_{ft} values, Table 4.1.1 & Appendix D.1), and average weather data (Table 1.4.3) are entered by the user in an APBSA simulation based on time. In an APBSA simulation based on time, five hundred iterations were run for a passed duration (D_p) of ten days for one distribution (Figure 5.6.2).

At the end of the above demonstration simulation based on time, the fraction of the total activity “Prep Deck 1” completed each week over the fraction of the total duration of the activity used each week (N_{ft}) was found to be 0.61 (mean value), which means that the current weekly actual unit duration of “Prep Deck 1” is more than what was given in the bid, and the weekly productivity is less than the baseline productivity in line with results of simulation based on cost (Figure 5.6.2). Consequently, the actual total

duration based on time (D_{at}) of the activity was found to be 47 work hours (6 work days) compared to 32 work hours (4 work days) in the bid and as a result the remaining duration (D_{rt}) was 37 work hours (5 work days).

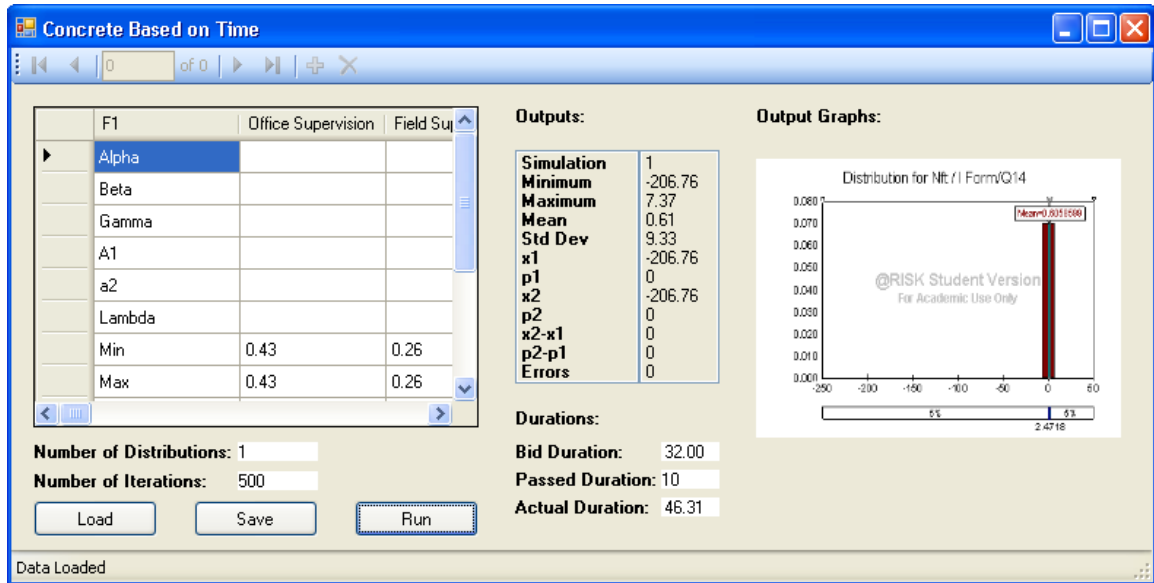


Figure 5.6.2 APBSA Simulation Based on Time Results Screen

5.7 APBSA Simulation Results

Actual total duration based on cost (D_{ac}) of critical path activity “Prep Deck 1” was found to be 34 work hours (5 work days) compared to 32 work hours (4 work days) in the bid and as a result the remaining duration (D_{rc}) was 24 work hours (3 work days). The total duration of the project extended 0.27% (1 day) from 365 to 366 days because of productivity delays (1 work day from 254 work days to 255 work days) in this activity. The 1 day difference between the bid and actual durations corresponds to a difference of \$11,207.86, which is 0.04% of the project’s budget. The dollar difference is found by

entering 365 days and 366 days as parameters for the bid and actual durations respectively into the regression equation 5.4.1.

$$-11,207.86 * 365 + 34,264,568.14 = \$30,173,699.24 \text{ for 365 days}$$

$$-11,207.86 * 366 + 34,264,568.14 = \$30,162,491.38 \text{ for 366 days}$$

$$\$30,173,699.24 - \$30,162,491.38 = \$11,207.86$$

Actual total duration based on time (D_{at}) of the same activity was found to be 47 work hours (6 work days) compared to 32 work hours (4 work days) in the bid and as a result the remaining duration (D_{rt}) was 37 work hours (5 work days). The total duration of the project extended 0.55% (2 days) from 365 to 367 days because of productivity delays (2 work days from 254 work days to 256 work days) in this activity. The 2 days difference between the bid and actual durations corresponds to a difference of \$22,415.72, which is 0.07% of the project's budget. This time, the dollar difference is found by entering 367 days as a parameter into the regression equation 5.4.1.

$$-11,207.86 * 367 + 34,264,568.14 = \$30,151,283.52 \text{ for 367 days}$$

$$\$30,173,699.24 - \$30,151,283.52 = \$22,415.72$$

One thing to keep in mind while considering these results is that these effects are only due to one simulation that represents productivity changes of one activity. If multiple simulations are ran parallel, duration and cost variances will differ more drastically on a large scale job with many activities that are running at the same time.

CHAPTER 6: CONCLUSION

Contractors not only must lower their prices to win the bids, but they may be subject to aggressive schedules and face possible delay damages. One tool that contractors have to alleviate these conditions is to improve the productivity of their labor. APBSA allows a company to predict, manage and even optimize the productivity associated with a project or levels of projects. APBSA is a dynamic scheduling system that stochastically utilizes weekly trended productivity data in order to automatically update the baseline schedule that was created at the beginning of the project by the construction manager. APBSA reports the construction activity duration variances and animates the progress of the job with most current data available in a 4-D environment. Contractors can improve their planning by utilizing APBSA with BIM which will help them to improve their craft productivity.

6.1 Research Contributions

A stochastic system that estimates future activity productivities by factoring in all the real-time affecting variables in order to update the baseline schedule is developed. During the research, a productivity database of trended construction activities was established, and correlation matrices (Appendix C) and probabilistic distribution functions (Appendix D) of these activities were developed in order to stochastically determine the impacts of each user-defined factor on the productivity indices of the activities.

Software components that read the contents of the trended construction activity database, and apply the productivity analysis results to the productivity rates were

developed. Software components that read baseline schedule activity durations, calculate actual activity durations, and update the schedule were developed. These components will be finally fed by Navisworks Manage (Bentley Navigator) to be utilized to animate the actual progress of the job versus the baseline schedule as shown in demonstration simulation based on time Figure 6.1.1.

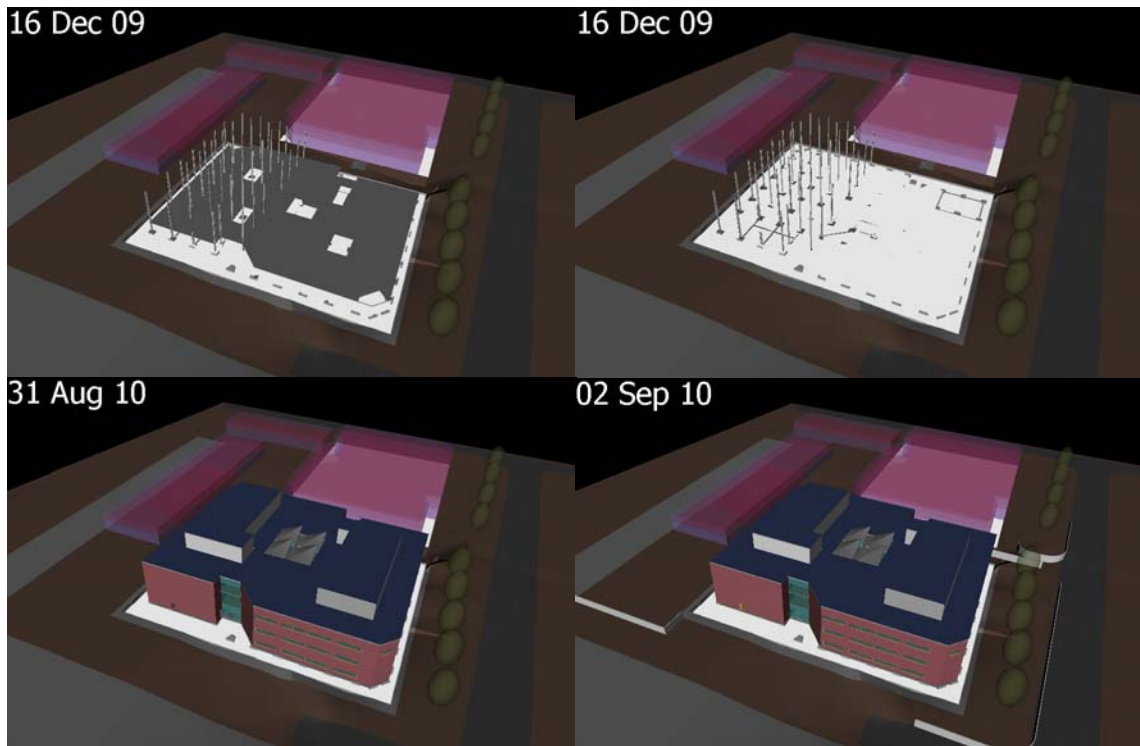


Figure 6.1.1 APBSA Simulation Navisworks Manage Schedule Comparison Screen

Simulations previously presented based on cost and time both resulted with actual duration being longer than the bid duration. This translates to poor productivity on the jobsite which will cause delays in the completion of the project. Due to these delays, direct (field supervision, safety, etc.) and indirect (overhead, office supervision, field office maintenance, etc.) costs will increase reducing the profitability of a project, and milestone dates that are critical both for the owner and the contractor will be missed

causing more losses, some of which are not recoverable. These delays may even lead to claims resulting in more time and money to be spent and increased losses of both entities at the end. All these turmoil scenarios can be avoided by early recognition of delays by the help of APBSA and taking necessary steps to boost craft productivity on the jobsite.

Claim Digger, which is a schedule analysis tool built-in Primavera Project Management module, was used to compare the real-time schedule and the associated baseline, and to determine what data has been modified. Claim Digger Comparison report generated by the Claim Digger (Figure 6.1.2) that compares data fields in revised SMEF III Real-Time based on time and corresponding original SMEF III (baseline project) can be found in Appendix E. It is important to keep in mind that this comparison report compares the baseline with an updated schedule due to a simulation with productivity effects on one activity. If multiple simulations were ran parallel for many activities that took place at the same time, duration and cost variances would even be more significant.

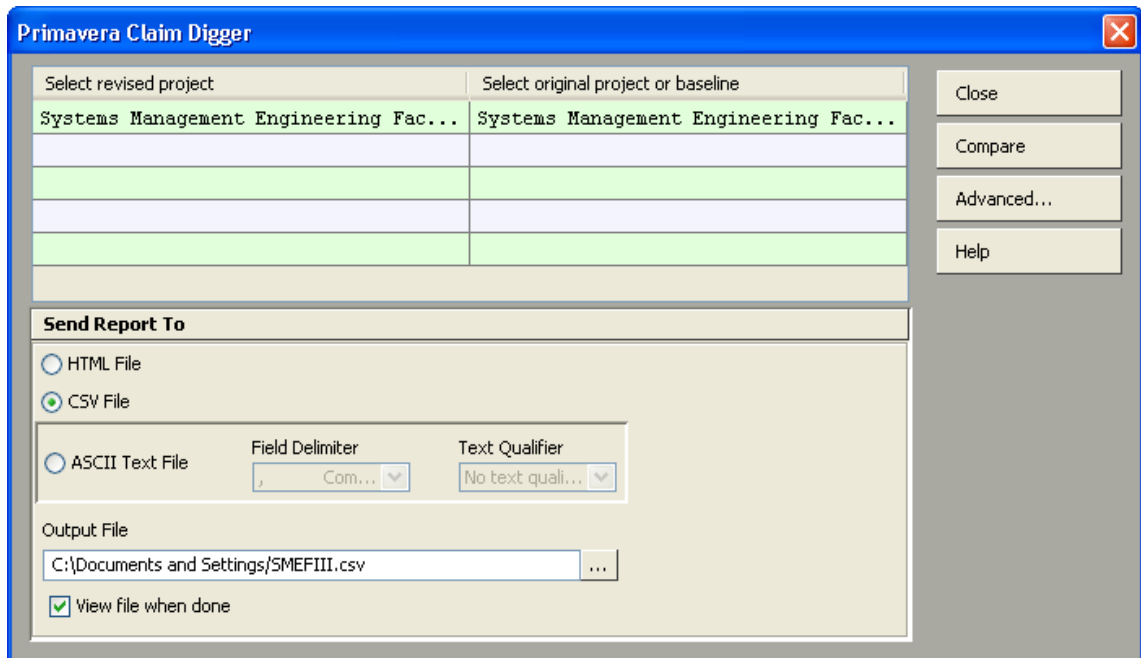


Figure 6.1.2 Primavera Claim Digger Real-Time and Baseline Schedule Comparison

6.2 Practicality Issues of APBSA

The accuracy of APBSA highly depends on the correctness of the weekly trend data that is being collected for the project. Unfortunately, those responsible for collecting such data often get sidetracked by other contemporaneous tasks and tend to skip a couple of weeks before reporting quantities for the activities that are completed. Poor weekly quantity reporting causes missing weekly trend data and noise that leads to distinct fluctuations.

This issue can easily be addressed for direct activities within the BIM model by using tags that blend RFID (Radio Frequency Identification) with GPS (Global Positioning System) or by simply giving the engineer percent complete check box options stating the completeness of an activity such as concrete pour of a structural element between two pre-modeled construction joints or the spool length of a placed pipe that is between two pre-modeled joints. It gets a little tricky tough to account for the indirect support activities (that goes with almost every major direct activity) like field supervision, mobilization, distribution of material, testing, QA/QC (quality assurance, quality control) inspections, house keeping and site clean-up after work is finished while reporting quantities.

6.3 Future Research Work

Trended cost and duration data from Newtown Creek Water Pollution Control Plant (WPCP) Upgrade were used to determine weekly productivity fractions for each activity. The validity of these productivity fractions should be confirmed by using different construction cost and duration databases.

Even though Navisworks Manage 2009 provides the support for customization through a set of COM (Component Object Model) interfaces to connect to the Navisworks application; not all the features available in the Navisworks application are supported by the Navisworks API (Application Programming Interface). Time Liner is one of the features that are not available in API yet [67]. Latest release of Digital Project TM V1, R4 of Gehry Technologies linkage should also be investigated for animation purposes.

APBSA v3.0 will import the anticipated and remaining quantities from AutoCAD Revit or Microstation Triforma software output xml format and compare it to the construction companies' trending software output. In the future once all these applications are tuned this data will be read from one source.

APBSA v3.0 will also be a web application that can be accessed via a web browser over a network such as the internet or an intranet at any time at any location. This way the most current field productivity data will easily be available to the executives and estimators from any remote location.

The present work investigates the productivity indices both based on time and cost for comparison reasons. Even though the fact that D_{at} and D_{ac} are both greater than D_t strengthens the validity of both demonstration simulations, simulation based on time results would be more accurate since unit cost of an activity might have changed due to factors other than the variations on productivity. Labor wage and material price escalations are two of these exterior factors that might have affected the unit cost of an activity. Further research should be done on the effects of two aforementioned factors on simulations based on cost.

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APPENDIX A

A.1 Weather Condition Data Comparison

A.1.1 Average Temperature (°F) Versus Date

A.1.2 Average Humidity versus Date

A.1.3 Average Dewpoint versus Date

A.1.4 Average Wind Speed versus Date

A.1.5 Average Pressure versus Date

A.2 Weather Event Data from station KNYNEWYO17 from:

A.2.1 1/8/2006 thru 6/25/2006

A.2.2 7/2/2006 thru 12/31/2006

A.2.3 1/7/2007 thru 6/24/2007

A.2.4 7/1/2007 thru 12/30/2007

A.2.5 1/6/2008 thru 6/29/2008

A.2.6 7/6/2008 thru 8/31/2008

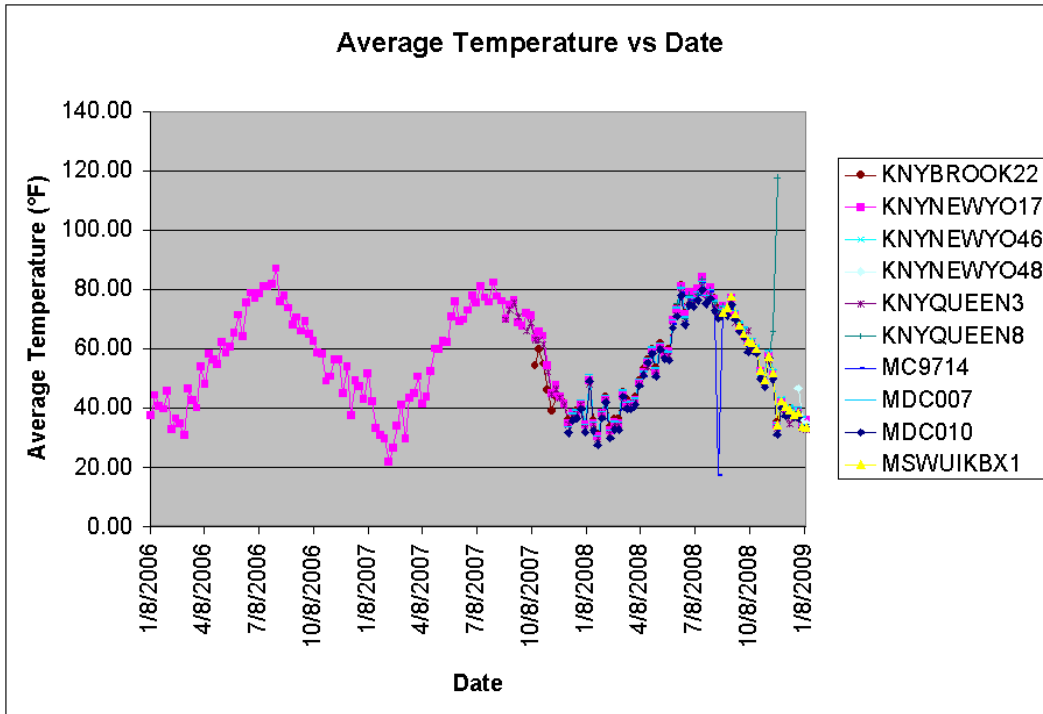


Figure A.1.1 Average Temperature (°F) versus Date

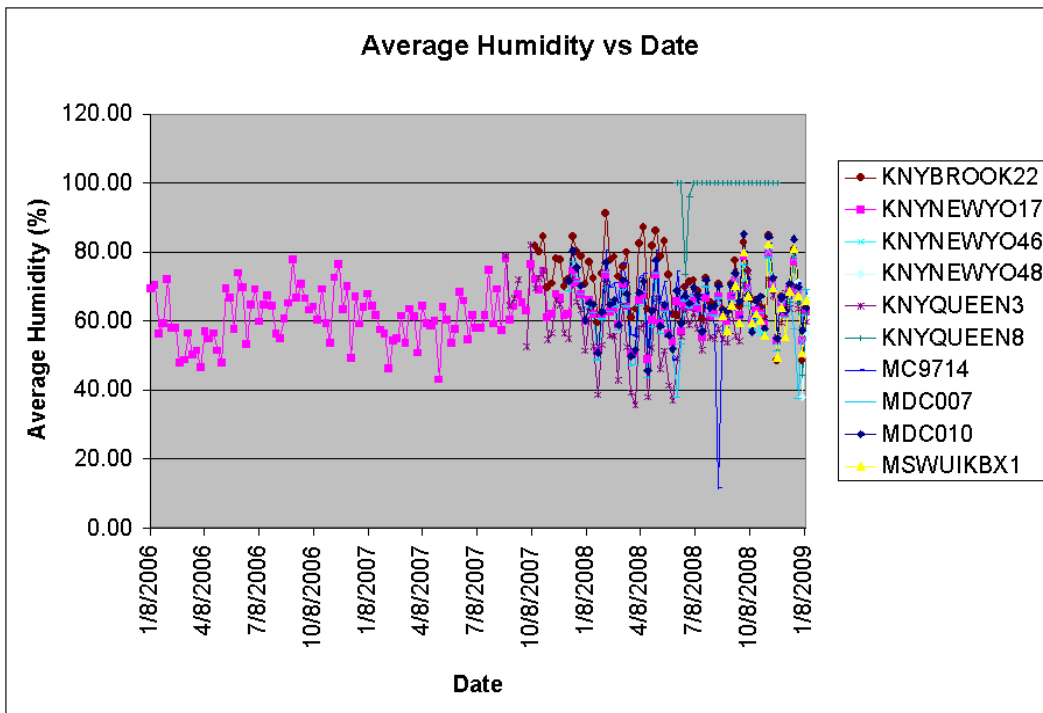


Figure A.1.2 Average Humidity versus Date

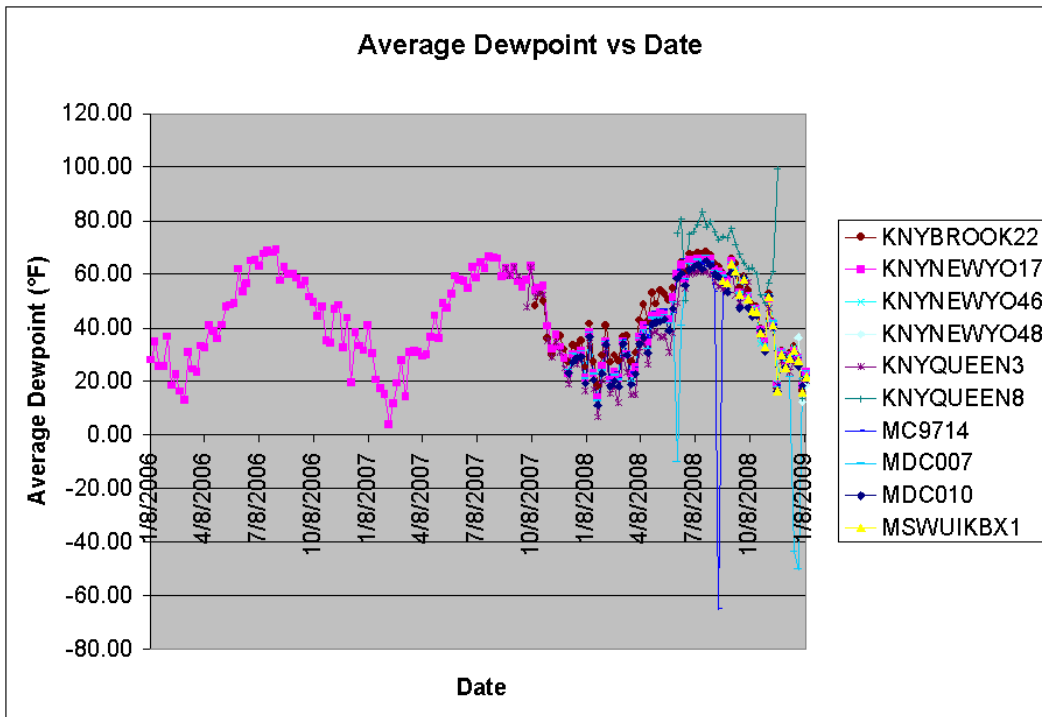


Figure A.1.3 Average Dewpoint versus Date

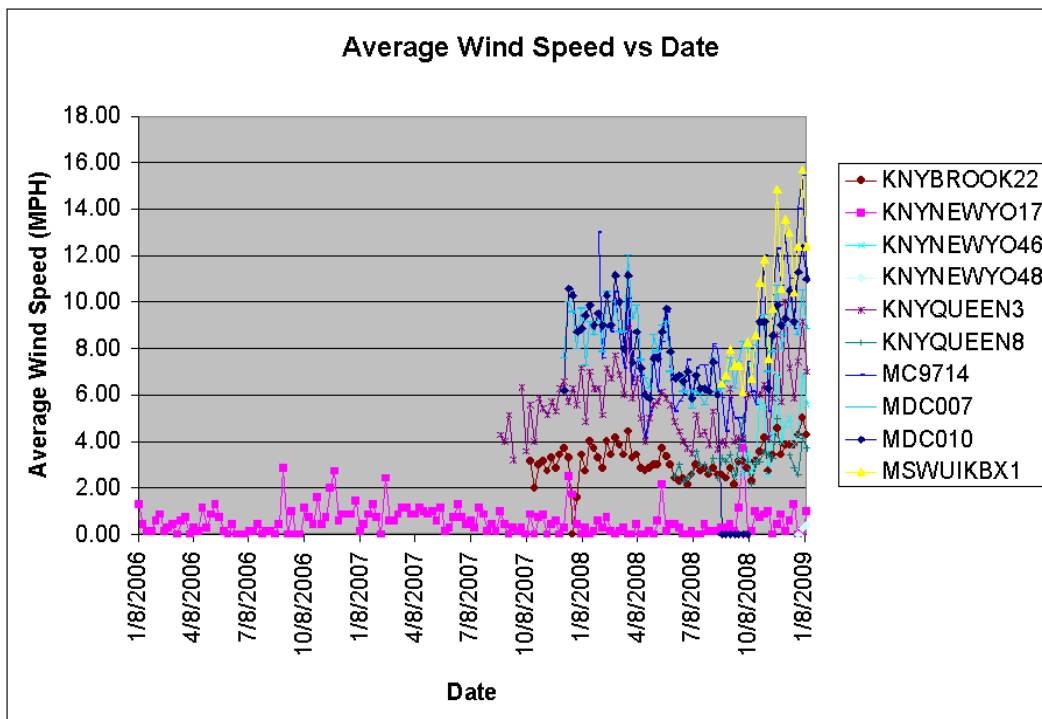


Figure A.1.4 Average Wind Speed versus Date

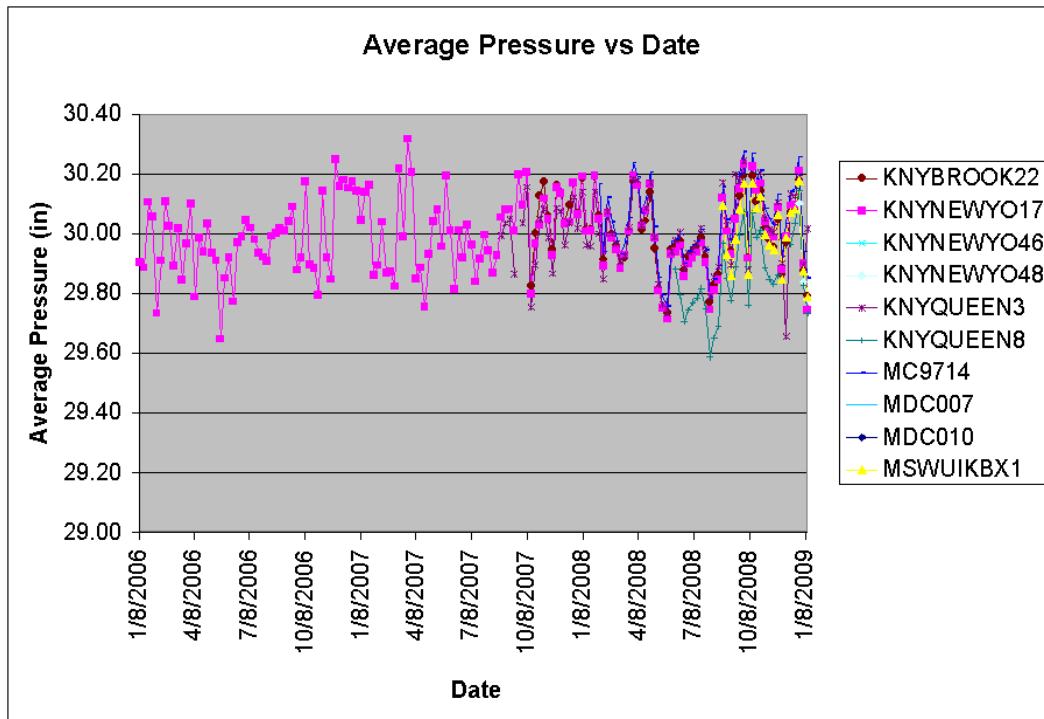


Figure A.1.5 Average Pressure versus Date

Week End Date	Temperature Average (F)	Dewpoint Average (F)	Humidity Average (%)	Pressure Average (IN)	Wind Speed Average (MPH)	Gust Speed Maximum (MPH)	Precipitation Sum (IN)
1/8/2006	37.43	28.00	69.29	29.90	1.29	19.71	0.37
1/15/2006	44.29	34.71	70.43	29.89	0.43	13.86	0.10
1/22/2006	40.43	25.57	56.29	30.10	0.14	22.71	0.04
1/29/2006	39.57	25.71	59.29	30.06	0.14	20.86	0.10
2/5/2006	45.57	36.71	72.00	29.73	0.57	20.29	0.16
2/12/2006	32.57	18.57	58.00	29.91	0.86	25.00	0.00
2/19/2006	36.43	22.57	58.00	30.11	0.14	17.71	0.01
2/26/2006	34.57	16.29	47.86	30.03	0.29	23.14	0.00
3/5/2006	30.71	13.00	48.71	29.89	0.43	25.00	0.01
3/12/2006	46.43	31.00	56.43	30.02	0.00	22.71	0.00
3/19/2006	42.43	24.57	50.29	29.85	0.57	23.14	0.00
3/26/2006	40.00	23.43	51.43	29.96	0.71	24.14	0.00
4/2/2006	53.86	33.29	46.57	30.10	0.00	21.00	0.00
4/9/2006	48.00	32.71	57.00	29.79	0.29	23.29	0.02
4/16/2006	58.14	40.86	54.71	29.99	0.14	19.57	0.00
4/23/2006	56.14	38.71	56.43	29.94	1.14	24.86	0.21
4/30/2006	54.71	35.86	51.43	30.03	0.29	23.29	0.01
5/7/2006	62.14	41.14	47.86	29.93	0.86	26.43	0.03
5/14/2006	58.57	47.71	69.29	29.91	1.29	26.43	0.09
5/21/2006	60.43	48.43	66.57	29.65	0.71	18.57	0.31
5/28/2006	65.29	49.29	57.71	29.85	0.14	15.29	0.00
6/4/2006	71.29	62.00	73.86	29.92	0.00	21.00	0.37
6/11/2006	64.00	53.43	69.57	29.77	0.43	23.43	0.21
6/18/2006	75.43	56.57	53.14	29.97	0.00	17.86	0.00
6/25/2006	78.71	65.00	64.57	29.99	0.00	15.29	0.03

Table A.2.1 Weather Event Data from station KNYNEWYO17 from 1/8/2006 thru 6/25/2006

Week End Date	Temperature Average (F)	Dewpoint Average (F)	Humidity Average (%)	Pressure Average (IN)	Wind Speed Average (MPH)	Gust Speed Maximum (MPH)	Precipitation Sum (IN)
7/2/2006	76.86	65.43	69.14	30.04	0.00	16.43	0.03
7/9/2006	78.57	63.00	59.71	30.02	0.14	17.57	0.10
7/16/2006	81.00	67.57	64.71	29.98	0.14	15.00	0.03
7/23/2006	81.00	68.57	67.43	29.93	0.43	20.29	0.22
7/30/2006	81.57	68.00	64.29	29.92	0.00	14.43	0.00
8/6/2006	87.00	69.14	56.29	29.91	0.14	21.29	0.00
8/13/2006	75.86	57.57	55.00	29.99	0.14	22.43	0.21
8/20/2006	77.86	62.57	60.71	30.00	0.00	15.29	0.00
8/27/2006	73.71	60.14	65.14	30.02	0.43	21.14	0.00
9/3/2006	67.86	60.14	77.71	30.01	2.86	27.00	0.22
9/10/2006	70.57	58.57	66.57	30.04	0.00	3.71	0.02
9/17/2006	65.86	55.86	70.57	30.09	1.00	22.71	0.23
9/24/2006	69.14	57.29	66.43	29.88	0.00	18.71	0.00
10/1/2006	64.71	51.57	63.14	29.92	0.00	24.86	0.00
10/8/2006	62.43	49.71	64.14	30.17	1.14	21.57	0.02
10/15/2006	58.57	44.29	60.29	29.89	0.71	22.57	0.30
10/22/2006	58.29	48.00	69.14	29.88	0.43	23.43	0.05
10/29/2006	49.00	35.14	59.29	29.79	1.57	26.71	0.11
11/5/2006	50.57	34.43	53.57	30.14	0.43	24.00	0.05
11/12/2006	56.29	47.00	72.57	29.92	0.71	25.29	0.33
11/19/2006	56.14	48.43	76.29	29.85	2.00	24.57	0.01
11/26/2006	44.86	32.71	63.29	30.25	2.71	27.00	0.08
12/3/2006	53.86	43.71	70.00	30.16	0.57	25.43	0.00
12/10/2006	37.43	19.71	49.29	30.18	0.86	25.14	0.00
12/17/2006	49.29	38.14	67.00	30.15	0.86	23.29	0.00
12/24/2006	47.14	33.29	59.14	30.17	0.86	25.86	0.11
12/31/2006	43.00	31.57	63.86	30.14	1.43	23.57	0.10

Table A.2.2 Weather Event Data from station KNYNEWYO17 from 7/2/2006 thru 12/31/2006

Week End Date	Temperature Average (F)	Dewpoint Average (F)	Humidity Average (%)	Pressure Average (IN)	Wind Speed Average (MPH)	Gust Speed Maximum (MPH)	Precipitation Sum (IN)
1/7/2007	51.43	40.71	67.86	30.04	0.14	18.57	0.05
1/14/2007	42.14	30.43	64.29	30.14	0.43	22.86	0.10
1/21/2007	33.00	20.71	61.57	30.16	0.86	26.14	0.03
1/28/2007	30.86	17.29	57.43	29.86	1.29	25.29	0.00
2/4/2007	29.43	15.14	56.29	29.89	0.71	22.71	0.01
2/11/2007	21.71	4.00	46.14	30.04	0.00	20.29	0.00
2/18/2007	26.43	11.71	54.14	29.87	2.43	24.57	0.00
2/25/2007	34.00	19.29	55.00	29.87	0.57	26.29	0.03
3/4/2007	41.00	27.71	61.43	29.82	0.57	21.00	0.27
3/11/2007	29.71	14.29	53.43	30.22	0.86	23.43	0.00
3/18/2007	43.29	31.00	63.43	29.99	1.14	20.00	0.13
3/25/2007	44.86	31.57	61.29	30.32	1.14	24.71	0.13
4/1/2007	50.57	31.00	50.71	30.20	0.86	42.57	0.01
4/8/2007	41.29	29.43	64.29	29.85	0.86	23.71	0.12
4/15/2007	43.57	29.86	59.29	29.89	1.14	26.29	0.43
4/22/2007	52.29	36.43	58.57	29.75	1.00	24.43	0.21
4/29/2007	60.00	44.57	59.86	29.93	0.86	23.57	0.15
5/6/2007	59.86	36.14	43.00	30.04	1.00	22.86	0.01
5/13/2007	62.57	49.29	63.86	30.08	0.57	26.57	0.01
5/20/2007	62.14	47.29	60.14	29.96	1.14	25.71	0.01
5/27/2007	70.71	52.57	53.57	30.19	0.14	18.43	0.00
6/3/2007	75.71	59.29	57.57	30.01	0.29	18.71	0.21
6/10/2007	69.14	57.71	68.29	29.81	0.71	21.86	1.13
6/17/2007	69.71	57.43	65.86	30.01	1.29	26.43	0.01
6/24/2007	72.86	54.71	54.57	29.92	0.71	26.14	0.03

Table A.2.3 Weather Event Data from station KNYNEWYO17 from 1/7/2007 thru 6/24/2007

Week End Date	Temperature Average (F)	Dewpoint Average (F)	Humidity Average (%)	Pressure Average (IN)	Wind Speed Average (MPH)	Gust Speed Maximum (MPH)	Precipitation Sum (IN)
7/1/2007	77.71	62.71	61.57	30.03	0.43	24.57	0.01
7/8/2007	75.43	58.86	57.86	29.96	0.57	24.14	0.01
7/15/2007	81.00	64.43	58.00	29.84	0.29	26.14	0.03
7/22/2007	77.14	62.29	61.57	29.92	1.14	27.57	0.11
7/29/2007	75.57	66.71	74.71	29.99	0.86	19.71	0.22
8/5/2007	82.29	66.00	59.14	29.94	0.14	18.57	0.05
8/12/2007	77.57	65.86	69.14	29.87	0.43	23.71	0.25
8/19/2007	76.00	59.14	57.14	29.93	0.14	18.14	0.01
8/26/2007	69.86	62.43	78.00	30.05	1.00	21.00	0.22
9/2/2007	74.57	59.71	60.14	30.08	0.43	20.43	0.00
9/9/2007	76.14	62.57	64.14	30.08	0.00	21.00	0.00
9/16/2007	68.71	57.14	67.57	30.01	0.29	18.57	0.03
9/23/2007	67.57	55.14	65.43	30.20	0.14	19.29	0.00
9/30/2007	71.86	58.00	62.86	30.10	0.29	18.86	0.00
10/7/2007	71.00	63.00	76.29	30.21	0.00	14.86	0.00
10/14/2007	63.43	53.86	72.00	29.80	0.86	22.86	0.27
10/21/2007	65.71	55.00	69.00	29.96	0.00	15.43	0.01
10/28/2007	64.25	55.75	74.50	30.03	0.75	18.50	0.13
11/4/2007	54.17	40.67	60.83	30.12	0.83	18.00	0.00
11/11/2007	45.00	32.29	61.86	30.05	0.00	21.29	0.10
11/18/2007	47.57	37.29	67.86	29.93	0.43	18.57	0.00
11/25/2007	43.71	32.86	66.71	30.15	0.57	18.57	0.06
12/2/2007	41.43	28.57	61.43	30.13	0.00	16.00	0.06
12/9/2007	34.71	23.00	62.00	30.03	0.29	20.57	0.04
12/16/2007	38.33	30.17	74.50	30.04	2.50	23.50	0.51
12/23/2007	38.29	29.29	71.14	30.17	1.71	25.29	0.14
12/30/2007	41.43	31.29	67.57	30.06	0.43	18.71	0.22

Table A.2.4 Weather Event Data from station KNYNEWYO17 from 7/1/2007 thru 12/30/2007

Week End Date	Temperature Average (F)	Dewpoint Average (F)	Humidity Average (%)	Pressure Average (IN)	Wind Speed Average (MPH)	Gust Speed Maximum (MPH)	Precipitation Sum (IN)
1/6/2008	34.14	21.29	60.00	30.19	0.00	15.86	0.04
1/13/2008	49.29	38.14	66.14	30.01	0.29	12.29	0.17
1/20/2008	34.86	23.00	62.00	30.01	0.00	16.00	0.24
1/27/2008	30.29	14.14	51.29	30.19	0.14	15.43	0.00
2/3/2008	38.29	25.71	61.57	30.05	0.57	39.86	0.21
2/10/2008	43.00	34.86	73.29	29.89	0.29	19.57	0.02
2/17/2008	32.29	20.71	62.71	30.07	0.71	22.86	0.22
2/24/2008	35.14	23.43	63.43	29.98	0.14	17.00	0.04
3/2/2008	34.71	21.29	58.86	29.95	0.00	16.57	0.03
3/9/2008	44.00	34.71	70.71	29.88	0.14	17.57	0.34
3/16/2008	41.57	30.00	64.14	29.93	0.29	15.57	0.05
3/23/2008	41.00	22.86	50.71	30.01	0.00	17.86	0.12
3/30/2008	42.43	25.14	51.00	30.19	0.00	15.57	0.00
4/6/2008	48.57	36.57	66.00	30.16	0.43	17.57	0.21
4/13/2008	52.00	41.00	67.71	30.03	0.00	11.86	0.06
4/20/2008	55.14	34.86	48.86	30.08	0.00	11.57	0.00
4/27/2008	59.43	44.43	60.14	30.17	0.14	15.29	0.00
5/4/2008	52.29	43.00	73.14	29.99	0.00	16.14	0.25
5/11/2008	60.71	45.57	59.29	29.81	0.57	9.14	0.22
5/18/2008	58.43	45.29	63.71	29.75	2.14	26.14	0.37
5/25/2008	59.14	43.00	56.29	29.71	0.14	24.14	0.06
6/1/2008	69.57	51.29	53.86	29.93	0.43	21.43	0.00
6/8/2008	73.00	60.00	65.57	29.94	0.43	19.00	0.05
6/15/2008	81.00	63.43	56.86	29.96	0.29	21.29	0.10
6/22/2008	71.57	58.43	64.43	29.86	0.00	22.00	0.00
6/29/2008	78.86	65.14	63.86	29.90	0.00	18.29	0.00

Table A.2.5 Weather Event Data from station KNYNEWYO17 from 1/6/2008 thru 6/29/2008

Week End Date	Temperature Average (F)	Dewpoint Average (F)	Humidity Average (%)	Pressure Average (IN)	Wind Speed Average (MPH)	Gust Speed Maximum (MPH)	Precipitation Sum (IN)
7/6/2008	77.71	64.71	66.57	29.92	0.14	21.86	0.01
7/13/2008	80.00	65.86	63.57	29.94	0.00	18.14	0.00
7/20/2008	84.14	65.71	55.14	29.97	0.00	17.00	0.04
7/27/2008	78.57	65.86	66.57	29.90	0.43	23.00	0.04
8/3/2008	80.57	65.57	61.14	29.74	0.14	23.14	0.01
8/10/2008	76.43	62.00	62.14	29.81	0.14	25.00	0.01
8/17/2008	72.86	61.00	67.14	29.85	0.14	22.57	0.08
8/24/2008	74.43	59.57	61.00	30.12	0.29	16.00	0.00
8/31/2008	73.14	57.71	59.71	30.01	0.29	24.71	0.10

Table A.2.6 Weather Event Data from station KNYNEWYO17 from 7/6/2008 thru 8/31/2008

APPENDIX B

B.1 Covariance Matrix

B.2 Cumulative Distribution Function (CDF)

B.3 Testing the Techniques

B.4 Frequency and Probability Distributions

B.5 Continuous versus Discrete Distributions

B.6 Fit Statistics and Ranking of Fits

B.7 Chi-Squared Statistic

Appendix B.1 Covariance Matrix

Covariance is a measure of how much two variables change together. Variance is a special case of the covariance when the two variables are identical. Covariance between the two variables will be positive if two variables tend to vary together. That is, when one of them is above its expected value, then the other variable tends to be above its expected value too. Covariance between the two variables will be negative if one of them tends to be above its expected value when the other variable is below its expected value.

The covariance matrix is a matrix of covariances between elements of a random vector.

If entries in the column vector

$$X = \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix}$$

are random variables, each with finite variance, then the covariance matrix Σ is the matrix whose (i, j) entry is the covariance

$$\sum_{ij} = \text{cov}(X_i, X_j) = E[(X_i - \mu_i)(X_j - \mu_j)]$$

where

$$\mu_i = E(X_i)$$

is the expected value of the i^{th} entry in the vector X . Thus,

$$\Sigma = \begin{bmatrix} E[(X_1 - \mu_1)(X_1 - \mu_1)] & E[(X_1 - \mu_1)(X_2 - \mu_2)] & \cdots & E[(X_1 - \mu_1)(X_n - \mu_n)] \\ E[(X_2 - \mu_2)(X_1 - \mu_1)] & E[(X_2 - \mu_2)(X_2 - \mu_2)] & \cdots & E[(X_2 - \mu_2)(X_n - \mu_n)] \\ \vdots & \vdots & \ddots & \vdots \\ E[(X_n - \mu_n)(X_1 - \mu_1)] & E[(X_n - \mu_n)(X_2 - \mu_2)] & \cdots & E[(X_n - \mu_n)(X_n - \mu_n)] \end{bmatrix}$$

Appendix B.2 Cumulative Distribution Function (CDF)

A cumulative distribution function gives the probability that an uncertain quantity is less than or equal to a specific value: $P(X \leq x)$ [27]. A cumulative curve is typically scaled from 0.0 to 1.0 (range of the possible random numbers generated during sampling) on the Y-axis, with Y-axis values representing the cumulative probability up to the corresponding X-axis value [11].

The 0.5 cumulative value (Fifty percent of the values in the distribution will fall below this median value and 50% will fall above) is the point of 50% cumulative probability ($0.5 = 50\%$) in a cumulative curve. The 0.0 cumulative value is the minimum value (Zero percent of the values will fall below this point) and the 1.0 cumulative value is the maximum value (Hundred percent of the values will fall below this point) [11].

The computer will generate a random number between 0 and 1 (with any number in the range equally likely to occur) which is then used to select a value from the cumulative curve in a typical Monte Carlo sampling sequence. More likely outcomes that are in the range where the cumulative curve is the "steepest" will be more likely to be sampled as the shape of the cumulative curve is based on the shape of the input probability distribution [11].

Appendix B.3 Testing the Techniques

Convergence concept is used to test a sampling method. Output distributions are stable and additional iterations do not markedly change the shape or statistics of the sampled distribution at the point of convergence. The sample mean versus the true mean, skewness, percentile probabilities and other statistics are often used as a measure of convergence [11].

Analyzing the number of iterations it takes the percentiles, mean and standard deviation to stabilize by using the built-in Convergence Monitoring capability in @RISK, Latin Hypercube sampling converges faster on the true distributions compared to Monte Carlo sampling [11].

Appendix B.4 Frequency and Probability Distributions

Frequency distribution is the term for output probability distribution and the input histogram distributions. It is constructed from data by arranging values into classes and representing the frequency of occurrence in any class by the height of the bar. The frequency of occurrence corresponds to probability [11].

A probability distribution or probability density function is the statistical term for a frequency distribution constructed from an infinitely large set of values where the class size is infinitesimally small [11].

Appendix B.5 Continuous Versus Discrete Distributions

First, it has to be decided if sample data is continuous or discrete. If data is specified as discrete, all data values must be integers. However, the converse is not true. Having all integral data values does not mean they only have to fit to discrete distributions. Discrete distributions always return integer values. If there is a set of data describing the number of heads in flipping a coin 100 times, discrete distributions would be fit to this set since partial outcomes are not allowed. Binomial and poisson distributions are discrete distributions. Continuous data, on the other hand, can take on any value in a range. If there is a set of data describing the weight, in pounds, of 100

people, continuous distributions would be fit to this data, since weights are not restricted to integral values. Normal, log-normal, t and F distributions are continuous distributions [11].

@RISK does not support the fitting of discrete distributions to density and cumulative curve data. Whether the data set is continuous or discrete can be specified in the “Input Data Options” dialog [11].

Appendix B.6 Fit Statistics and Ranking of Fits

@RISK reports one or more fit statistics, which measure how good the distribution fits the input data, for each fit. The smaller the value, the better the fit for each of these statistics. Chi-squared, Kolmogorov-Smirnov, Anderson-Darling, and Root-Mean Squared Error are four different fit statistics that @RISK makes use of [11].

It must be decided which information is most important when considering which test will give the "best" result since each test has its strengths and weaknesses [11].

@RISK ranks all the fitted distributions using one or more fit statistics. Fits can be ranked by their chi-squared, Anderson-Darling, or Kolmogorov-Smirnov statistic for continuous sample data. Only the chi-squared statistic can be used for discrete sample data. The fits are ranked by their RMS Error value for density and cumulative curve data [11].

Appendix B.7 Chi-Squared Statistic

The chi-squared statistic is the best known goodness-of-fit statistic which can be used with both continuous and discrete sample data. The x-axis domain must first be

broken up into several “bins” to calculate the chi-squared statistic. The chi-squared statistic is defined as:

$$X^2 = \sum_{i=1}^K \frac{(N_i - E_i)^2}{E_i}$$

where

K = the number of bins

N_i = the observed number of samples in the i^{th} bin

E_i = the expected number of samples in the i^{th} bin

Having no clear guidelines for selecting the number and location of the bins is a weakness of the chi-squared statistic. In some situations, different conclusions can be reached from the same data depending on how the bins are specified [11].

Some of the arbitrariness of the bin selection can be removed by using equiprobable bins in @RISK. For continuous distributions @RISK adjusts the bin sizes based on the fitted distribution, trying to make each bin contain an equal amount of probability. However, for discrete distributions, @RISK only makes the bins approximately equal. @RISK settings allows full control of how bins are defined for the chi-squared test in the “Define Chi-Squared Binning” dialog [11].

APPENDIX C

C.1 Correlation Matrices Based on Cost for:

C.1.1 Concrete

C.1.2 Excavation

C.1.3 Change Orders

C.1.4 Unit Prices

C.1.5 Cut-Off, Haul & Dispose Piles

C.1.6 Concrete Demolition

C.1.7 Metal

C.1.8 Mechanical

C.1.9 Architectural

C.2 Correlation Matrices Based on Time for:

C.2.1 Concrete

C.2.2 Excavation

C.2.3 Change Orders

C.2.4 Unit Prices

C.2.5 Cut-Off, Haul & Dispose Piles

C.2.6 Concrete Demolition

C.2.7 Metal

C.2.8 Mechanical

C.2.9 Architectural

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.268	0.021	0.281	0.205	0.219	0.200	0.078	0.012	0.048	0.241
Field Supervision	0.268	1.000	-0.073	0.613	0.399	0.626	0.433	0.233	-0.009	0.098	0.609
Carpenter Foreman	0.021	-0.073	1.000	-0.185	0.017	-0.316	0.387	-0.052	0.030	0.089	-0.363
Master Mechanic & Maintenance Foreman	0.281	0.613	-0.185	1.000	0.628	0.913	0.554	0.081	-0.025	0.121	0.899
Fuel, Oil, Grease for Equipment	0.205	0.399	0.017	0.628	1.000	0.585	0.496	0.291	-0.028	0.119	0.572
Labor Shop Steward	0.219	0.626	-0.316	0.913	0.585	1.000	0.496	0.046	-0.011	0.057	0.957
Teamsters	0.200	0.433	0.387	0.554	0.496	0.496	1.000	0.000	0.022	0.345	0.437
Offsite Yard Crew	0.078	0.233	-0.052	0.081	0.291	0.046	0.000	1.000	-0.014	-0.002	0.058
Survey Party	0.012	-0.009	0.030	-0.025	-0.028	-0.011	0.022	-0.014	1.000	-0.003	0.026
Maintain Field Office	0.048	0.098	0.089	0.121	0.119	0.057	0.345	-0.002	-0.003	1.000	0.053
Maintenance & Protection of Traffic	0.241	0.609	-0.363	0.899	0.572	0.957	0.437	0.058	0.026	0.053	1.000
Temporary Access & Maintenance	0.018	0.028	-0.002	0.032	-0.019	0.038	-0.036	0.007	-0.006	0.004	0.021
Dewatering	0.005	-0.004	-0.001	-0.003	0.011	-0.008	-0.006	0.175	-0.006	0.023	-0.010
Crane Support	0.106	0.699	0.044	-0.012	-0.034	-0.006	0.026	0.283	-0.010	-0.018	-0.029
Furnish Concrete	-0.098	-0.269	0.181	-0.398	-0.250	-0.427	-0.176	0.119	0.000	0.006	-0.432
Install Form	0.027	0.065	0.150	0.048	0.026	0.035	0.096	-0.009	0.010	0.017	0.038
Install Rebar	0.003	0.000	-0.117	0.018	-0.044	0.022	-0.072	0.021	-0.010	-0.005	0.010
Pour Concrete	0.007	0.005	0.010	0.013	0.018	0.007	0.007	-0.013	-0.007	-0.006	-0.002
Finish Concrete	-0.008	-0.013	-0.029	-0.012	0.000	-0.003	-0.024	-0.017	-0.006	0.004	0.008
Furnish & Install Grout	-0.031	-0.011	-0.120	-0.040	-0.141	-0.017	-0.050	-0.015	-0.002	-0.002	0.002
Average Temperature (F)	-0.118	-0.058	0.070	-0.130	-0.064	-0.049	0.013	-0.042	0.057	-0.080	-0.120
Average Dewpoint (F)	-0.132	-0.074	0.064	-0.145	-0.071	-0.057	0.018	-0.048	0.088	-0.073	-0.127
Average Humidity (%)	-0.097	-0.102	-0.002	-0.127	-0.063	-0.070	0.029	-0.041	0.187	0.012	-0.088
Average Pressure (IN)	-0.073	-0.133	-0.084	-0.103	-0.104	-0.092	-0.041	0.222	0.012	0.074	-0.084
Average Wind Speed (MPH)	0.086	-0.030	0.063	-0.025	-0.020	-0.020	0.100	0.066	0.344	-0.028	0.025
Maximum Gust Speed (MPH)	0.311	-0.021	-0.015	0.081	0.072	0.057	0.003	0.038	0.104	-0.058	0.111
Precipitation Sum (IN)	0.010	-0.069	-0.019	-0.086	-0.029	-0.052	0.013	-0.021	0.074	-0.020	-0.081

Table C.1.1.1 Concrete Correlation Matrix Based on Cost

Activity	Temporary Access & Maintenance	Dewatering	Concrete Support	Furnish Concrete	Install Form	Install Rebar	Place Concrete	Finish Concrete	Furnish & Install Grout	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.018	0.005	0.106	-0.098	0.027	0.003	0.007	-0.008	-0.031	-0.118	-0.132	-0.097	-0.073	0.086	0.311	0.010
Field Supervision	0.028	-0.004	0.699	-0.269	0.065	0.000	0.005	-0.013	-0.011	-0.058	-0.074	-0.102	-0.133	-0.030	-0.021	-0.069
Carpenter Foreman	-0.002	-0.001	0.044	0.181	0.150	-0.117	0.010	-0.029	-0.120	0.070	0.064	-0.002	-0.084	0.063	-0.015	-0.019
Master Mechanic & Maintenance Foreman	0.032	-0.003	-0.012	-0.398	0.048	0.018	0.013	-0.012	-0.040	-0.130	-0.145	-0.127	-0.103	-0.025	0.081	-0.086
Fuel, Oil, Grease for Equipment	-0.019	0.011	-0.034	-0.250	0.026	-0.044	0.018	0.000	-0.141	-0.064	-0.071	-0.063	-0.104	-0.020	0.072	-0.029
Labor Shop Steward	0.038	-0.008	-0.006	-0.427	0.035	0.022	0.007	-0.003	-0.017	-0.049	-0.057	-0.070	-0.092	-0.020	0.057	-0.052
Teamsters	-0.036	-0.006	0.026	-0.176	0.096	-0.072	0.007	-0.024	-0.050	0.013	0.018	0.029	-0.041	0.100	0.003	0.013
Offsite Yard Crew	0.007	0.175	0.283	0.119	-0.009	0.021	-0.013	-0.017	-0.015	-0.042	-0.048	-0.041	0.222	0.066	0.038	-0.021
Survey Party	-0.006	-0.006	-0.010	0.000	0.010	-0.010	-0.007	-0.006	-0.002	0.057	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	0.004	0.023	-0.018	0.006	0.017	-0.005	-0.006	0.004	-0.002	-0.080	-0.073	0.012	0.074	-0.028	-0.058	-0.020
Maintenance & Protection of Traffic	0.021	-0.010	-0.029	-0.432	0.038	0.010	-0.002	0.008	0.002	-0.120	-0.127	-0.088	-0.084	0.025	0.111	-0.081
Temporary Access & Maintenance	1.000	-0.005	-0.011	-0.019	-0.033	0.941	-0.007	-0.207	-0.002	0.105	0.095	-0.031	0.006	-0.073	-0.065	0.004
Dewatering	-0.005	1.000	-0.010	0.880	0.020	-0.003	-0.006	-0.002	0.000	0.058	0.035	-0.100	0.131	-0.056	-0.048	-0.055
Crane Support	-0.011	-0.010	1.000	-0.023	0.029	-0.012	-0.009	0.080	0.001	0.040	0.029	-0.041	-0.042	-0.043	-0.088	-0.083
Furnish Concrete	-0.019	0.880	-0.023	1.000	0.006	-0.010	-0.005	0.002	0.006	0.129	0.107	-0.068	0.131	-0.075	-0.094	-0.026
Install Form	-0.033	0.020	0.029	0.006	1.000	-0.206	0.012	0.107	0.211	-0.032	-0.042	-0.060	0.001	-0.005	-0.001	0.021
Install Rebar	0.941	-0.003	-0.012	-0.010	-0.206	1.000	-0.005	-0.226	-0.013	0.076	0.070	-0.016	0.006	-0.035	-0.077	0.008
Pour Concrete	-0.007	-0.006	-0.009	-0.005	0.012	-0.005	1.000	-0.004	0.004	-0.074	-0.067	0.017	0.001	0.089	-0.020	0.022
Finish Concrete	-0.207	-0.002	0.080	0.002	0.107	-0.226	-0.004	1.000	0.007	0.027	0.040	0.067	-0.109	-0.032	0.057	0.006
Furnish & Install Grout	-0.002	0.000	0.001	0.006	0.211	-0.013	0.004	0.007	1.000	0.067	0.075	0.074	-0.100	0.069	-0.025	0.066
Average Temperature (F)	0.105	0.058	0.040	0.129	-0.032	0.076	-0.074	0.027	0.067	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.095	0.035	0.029	0.107	-0.042	0.070	-0.067	0.040	0.075	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.031	-0.100	-0.041	-0.068	-0.060	-0.016	0.017	0.067	0.074	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.006	0.131	-0.042	0.131	0.001	0.006	0.001	-0.109	-0.100	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.073	-0.056	-0.043	-0.075	-0.005	-0.035	0.089	-0.032	0.069	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	-0.048	-0.088	-0.094	-0.001	-0.077	-0.020	0.057	-0.025	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	-0.055	-0.083	-0.026	0.021	0.008	0.022	0.006	0.066	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.1.1.2 Concrete Correlation Matrix Based on Cost

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.268	0.021	0.281	0.205	0.219	0.200	0.078	0.012	0.048	0.241
Field Supervision	0.268	1.000	-0.073	0.613	0.399	0.626	0.433	0.233	-0.009	0.098	0.609
Carpenter Foreman	0.021	-0.073	1.000	-0.185	0.017	-0.316	0.387	-0.052	0.030	0.089	-0.363
Master Mechanic & Maintenance Foreman	0.281	0.613	-0.185	1.000	0.628	0.913	0.554	0.081	-0.025	0.121	0.899
Fuel, Oil, Grease for Equipment	0.205	0.399	0.017	0.628	1.000	0.585	0.496	0.291	-0.028	0.119	0.572
Labor Shop Steward	0.219	0.626	-0.316	0.913	0.585	1.000	0.496	0.046	-0.011	0.057	0.957
Teamsters	0.200	0.433	0.387	0.554	0.496	0.496	1.000	0.000	0.022	0.345	0.437
Offsite Yard Crew	0.078	0.233	-0.052	0.081	0.291	0.046	0.000	1.000	-0.014	-0.002	0.058
Survey Party	0.012	-0.009	0.030	-0.025	-0.028	-0.011	0.022	-0.014	1.000	-0.003	0.026
Maintain Field Office	0.048	0.098	0.089	0.121	0.119	0.057	0.345	-0.002	-0.003	1.000	0.053
Maintenance & Protection of Traffic	0.241	0.609	-0.363	0.899	0.572	0.957	0.437	0.058	0.026	0.053	1.000
Temporary Access & Maintenance	0.018	0.028	-0.002	0.032	-0.019	0.038	-0.036	0.007	-0.006	0.004	0.021
SOE	-0.020	-0.131	-0.053	0.013	0.046	-0.036	0.007	-0.015	0.003	0.100	0.002
Dewatering	0.005	-0.004	-0.001	-0.003	0.011	-0.008	-0.006	0.175	-0.006	0.023	-0.010
Crane Support	0.106	0.699	0.044	-0.012	-0.034	-0.006	0.026	0.283	-0.010	-0.018	-0.029
Excavation	-0.013	0.073	-0.144	-0.105	-0.106	-0.056	-0.353	0.028	0.001	-0.009	-0.001
Fills & Backfills	-0.007	0.094	-0.133	0.023	-0.056	0.040	-0.115	0.010	0.005	0.049	0.045
Average Temperature (F)	-0.118	-0.058	0.070	-0.130	-0.064	-0.049	0.013	-0.042	0.057	-0.080	-0.120
Average Dewpoint (F)	-0.132	-0.074	0.064	-0.145	-0.071	-0.057	0.018	-0.048	0.088	-0.073	-0.127
Average Humidity (%)	-0.097	-0.102	-0.002	-0.127	-0.063	-0.070	0.029	-0.041	0.187	0.012	-0.088
Average Pressure (IN)	-0.073	-0.133	-0.084	-0.103	-0.104	-0.092	-0.041	0.222	0.012	0.074	-0.084
Average Wind Speed (MPH)	0.086	-0.030	0.063	-0.025	-0.020	-0.020	0.100	0.066	0.344	-0.028	0.025
Maximum Gust Speed (MPH)	0.311	-0.021	-0.015	0.081	0.072	0.057	0.003	0.038	0.104	-0.058	0.111
Precipitation Sum (IN)	0.010	-0.069	-0.019	-0.086	-0.029	-0.052	0.013	-0.021	0.074	-0.020	-0.081

Table C.1.2.1 Excavation Correlation Matrix Based on Cost

Activity	Temporary Access & Maintenance	SOE	Dewatering	Crane Support	Excavation	Fills & Backfills	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.018	-0.020	0.005	0.106	-0.013	-0.007	-0.118	-0.132	-0.097	-0.073	0.086	0.311	0.010
Field Supervision	0.028	-0.131	-0.004	0.699	0.073	0.094	-0.058	-0.074	-0.102	-0.133	-0.030	-0.021	-0.069
Carpenter Foreman	-0.002	-0.053	-0.001	0.044	-0.144	-0.133	0.070	0.064	-0.002	-0.084	0.063	-0.015	-0.019
Master Mechanic & Maintenance Foreman	0.032	0.013	-0.003	-0.012	-0.105	0.023	-0.130	-0.145	-0.127	-0.103	-0.025	0.081	-0.086
Fuel, Oil, Grease for Equipment	-0.019	0.046	0.011	-0.034	-0.106	-0.056	-0.064	-0.071	-0.063	-0.104	-0.020	0.072	-0.029
Labor Shop Steward	0.038	-0.036	-0.008	-0.006	-0.056	0.040	-0.049	-0.057	-0.070	-0.092	-0.020	0.057	-0.052
Teamsters	-0.036	0.007	-0.006	0.026	-0.353	-0.115	0.013	0.018	0.029	-0.041	0.100	0.003	0.013
Offsite Yard Crew	0.007	-0.015	0.175	0.283	0.028	0.010	-0.042	-0.048	-0.041	0.222	0.066	0.038	-0.021
Survey Party	-0.006	0.003	-0.006	-0.010	0.001	0.005	0.057	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	0.004	0.100	0.023	-0.018	-0.009	0.049	-0.080	-0.073	0.012	0.074	-0.028	-0.058	-0.020
Protection of Traffic	0.021	0.002	-0.010	-0.029	-0.001	0.045	-0.120	-0.127	-0.088	-0.084	0.025	0.111	-0.081
Temporary Access & Maintenance	1.000	0.038	-0.005	-0.011	0.008	0.009	0.105	0.095	-0.031	0.006	-0.073	-0.065	0.004
SOE	0.038	1.000	0.216	-0.156	-0.121	-0.024	-0.056	-0.049	0.029	-0.004	-0.168	-0.055	0.022
Dewatering	-0.005	0.216	1.000	-0.010	-0.196	-0.096	0.058	0.035	-0.100	0.131	-0.056	-0.048	-0.055
Crane Support	-0.011	-0.156	-0.010	1.000	0.182	0.111	0.040	0.029	-0.041	-0.042	-0.043	-0.088	-0.083
Excavation	0.008	-0.121	-0.196	0.182	1.000	0.118	-0.096	-0.105	-0.067	0.024	0.009	0.040	-0.057
Fills & Backfills	0.009	-0.024	-0.096	0.111	0.118	1.000	-0.094	-0.085	0.016	0.002	0.043	0.106	0.032
Average Temperature (F)	0.105	-0.056	0.058	0.040	-0.096	-0.094	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.095	-0.049	0.035	0.029	-0.105	-0.085	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.031	0.029	-0.100	-0.041	-0.067	0.016	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.006	-0.004	0.131	-0.042	0.024	0.002	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.073	-0.168	-0.056	-0.043	0.009	0.043	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	-0.055	-0.048	-0.088	0.040	0.106	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	0.022	-0.055	-0.083	-0.057	0.032	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.1.2.2 Excavation Correlation Matrix Based on Cost

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.268	0.021	0.281	0.205	0.219	0.200	0.078	0.012	0.048	0.241
Field Supervision	0.268	1.000	-0.073	0.613	0.399	0.626	0.433	0.233	-0.009	0.098	0.609
Carpenter Foreman	0.021	-0.073	1.000	-0.185	0.017	-0.316	0.387	-0.052	0.030	0.089	-0.363
Master Mechanic & Maintenance Foreman	0.281	0.613	-0.185	1.000	0.628	0.913	0.554	0.081	-0.025	0.121	0.899
Fuel, Oil, Grease for Equipment	0.205	0.399	0.017	0.628	1.000	0.585	0.496	0.291	-0.028	0.119	0.572
Labor Shop Steward	0.219	0.626	-0.316	0.913	0.585	1.000	0.496	0.046	-0.011	0.057	0.957
Teamsters	0.200	0.433	0.387	0.554	0.496	0.496	1.000	0.000	0.022	0.345	0.437
Offsite Yard Crew	0.078	0.233	-0.052	0.081	0.291	0.046	0.000	1.000	-0.014	-0.002	0.058
Survey Party	0.012	-0.009	0.030	-0.025	-0.028	-0.011	0.022	-0.014	1.000	-0.003	0.026
Maintain Field Office	0.048	0.098	0.089	0.121	0.119	0.057	0.345	-0.002	-0.003	1.000	0.053
Maintenance & Protection of Traffic	0.241	0.609	-0.363	0.899	0.572	0.957	0.437	0.058	0.026	0.053	1.000
Temporary Access & Maintenance	0.018	0.028	-0.002	0.032	-0.019	0.038	-0.036	0.007	-0.006	0.004	0.021
Dewatering	0.005	-0.004	-0.001	-0.003	0.011	-0.008	-0.006	0.175	-0.006	0.023	-0.010
Crane Support	0.106	0.699	0.044	-0.012	-0.034	-0.006	0.026	0.283	-0.010	-0.018	-0.029
Change Orders	0.232	0.622	-0.368	0.909	0.600	0.971	0.436	0.057	-0.008	0.060	0.973
Average Temperature (F)	-0.118	-0.058	0.070	-0.130	-0.064	-0.049	0.013	-0.042	0.057	-0.080	-0.120
Average Dewpoint (F)	-0.132	-0.074	0.064	-0.145	-0.071	-0.057	0.018	-0.048	0.088	-0.073	-0.127
Average Humidity (%)	-0.097	-0.102	-0.002	-0.127	-0.063	-0.070	0.029	-0.041	0.187	0.012	-0.088
Average Pressure (IN)	-0.073	-0.133	-0.084	-0.103	-0.104	-0.092	-0.041	0.222	0.012	0.074	-0.084
Average Wind Speed (MPH)	0.086	-0.030	0.063	-0.025	-0.020	-0.020	0.100	0.066	0.344	-0.028	0.025
Maximum Gust Speed (MPH)	0.311	-0.021	-0.015	0.081	0.072	0.057	0.003	0.038	0.104	-0.058	0.111
Precipitation Sum (IN)	0.010	-0.069	-0.019	-0.086	-0.029	-0.052	0.013	-0.021	0.074	-0.020	-0.081

Table C.1.3.1 Change Order Correlation Matrix Based on Cost

Activity	Dewatering	Concrete Support	Change Orders	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.005	0.106	0.232	-0.118	-0.132	-0.097	-0.073	0.086	0.311	0.010
Field Supervision	-0.004	0.699	0.622	-0.058	-0.074	-0.102	-0.133	-0.030	-0.021	-0.069
Carpenter Foreman	-0.001	0.044	-0.368	0.070	0.064	-0.002	-0.084	0.063	-0.015	-0.019
Master Mechanic & Maintenance Foreman	-0.003	-0.012	0.909	-0.130	-0.145	-0.127	-0.103	-0.025	0.081	-0.086
Fuel, Oil, Grease for Equipment	0.011	-0.034	0.600	-0.064	-0.071	-0.063	-0.104	-0.020	0.072	-0.029
Labor Shop Steward	-0.008	-0.006	0.971	-0.049	-0.057	-0.070	-0.092	-0.020	0.057	-0.052
Teamsters	-0.006	0.026	0.436	0.013	0.018	0.029	-0.041	0.100	0.003	0.013
Offsite Yard Crew	0.175	0.283	0.057	-0.042	-0.048	-0.041	0.222	0.066	0.038	-0.021
Survey Party	-0.006	-0.010	-0.008	0.057	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	0.023	-0.018	0.060	-0.080	-0.073	0.012	0.074	-0.028	-0.058	-0.020
Maintenance & Protection of Traffic	-0.010	-0.029	0.973	-0.120	-0.127	-0.088	-0.084	0.025	0.111	-0.081
Temporary Access & Maintenance	-0.005	-0.011	0.032	0.105	0.095	-0.031	0.006	-0.073	-0.065	0.004
Dewatering	1.000	-0.010	-0.075	0.058	0.035	-0.100	0.131	-0.056	-0.048	-0.055
Crane Support	-0.010	1.000	-0.019	0.040	0.029	-0.041	-0.042	-0.043	-0.088	-0.083
Change Orders	-0.075	-0.019	1.000	-0.124	-0.128	-0.075	-0.087	0.009	0.095	-0.037
Average Temperature (F)	0.058	0.040	-0.124	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.035	0.029	-0.128	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.100	-0.041	-0.075	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.131	-0.042	-0.087	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.056	-0.043	0.009	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.048	-0.088	0.095	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	-0.055	-0.083	-0.037	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.1.3.2 Change Order Correlation Matrix Based on Cost

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.268	0.021	0.281	0.205	0.219	0.200	0.078	0.012	0.048	0.241
Field Supervision	0.268	1.000	-0.073	0.613	0.399	0.626	0.433	0.233	-0.009	0.098	0.609
Carpenter Foreman	0.021	-0.073	1.000	-0.185	0.017	-0.316	0.387	-0.052	0.030	0.089	-0.363
Master Mechanic & Maintenance Foreman	0.281	0.613	-0.185	1.000	0.628	0.913	0.554	0.081	-0.025	0.121	0.899
Fuel, Oil, Grease for Equipment	0.205	0.399	0.017	0.628	1.000	0.585	0.496	0.291	-0.028	0.119	0.572
Labor Shop Steward	0.219	0.626	-0.316	0.913	0.585	1.000	0.496	0.046	-0.011	0.057	0.957
Teamsters	0.200	0.433	0.387	0.554	0.496	0.496	1.000	0.000	0.022	0.345	0.437
Offsite Yard Crew	0.078	0.233	-0.052	0.081	0.291	0.046	0.000	1.000	-0.014	-0.002	0.058
Survey Party	0.012	-0.009	0.030	-0.025	-0.028	-0.011	0.022	-0.014	1.000	-0.003	0.026
Maintain Field Office	0.048	0.098	0.089	0.121	0.119	0.057	0.345	-0.002	-0.003	1.000	0.053
Maintenance & Protection of Traffic	0.241	0.609	-0.363	0.899	0.572	0.957	0.437	0.058	0.026	0.053	1.000
Temporary Access & Maintenance	0.018	0.028	-0.002	0.032	-0.019	0.038	-0.036	0.007	-0.006	0.004	0.021
Dewatering	0.005	-0.004	-0.001	-0.003	0.011	-0.008	-0.006	0.175	-0.006	0.023	-0.010
Crane Support	0.106	0.699	0.044	-0.012	-0.034	-0.006	0.026	0.283	-0.010	-0.018	-0.029
Unit Price	0.077	0.387	-0.038	0.025	-0.021	0.068	-0.003	0.270	-0.017	-0.125	0.026
Average Temperature (F)	-0.118	-0.058	0.070	-0.130	-0.064	-0.049	0.013	-0.042	0.057	-0.080	-0.120
Average Dewpoint (F)	-0.132	-0.074	0.064	-0.145	-0.071	-0.057	0.018	-0.048	0.088	-0.073	-0.127
Average Humidity (%)	-0.097	-0.102	-0.002	-0.127	-0.063	-0.070	0.029	-0.041	0.187	0.012	-0.088
Average Pressure (IN)	-0.073	-0.133	-0.084	-0.103	-0.104	-0.092	-0.041	0.222	0.012	0.074	-0.084
Average Wind Speed (MPH)	0.086	-0.030	0.063	-0.025	-0.020	-0.020	0.100	0.066	0.344	-0.028	0.025
Maximum Gust Speed (MPH)	0.311	-0.021	-0.015	0.081	0.072	0.057	0.003	0.038	0.104	-0.058	0.111
Precipitation Sum (IN)	0.010	-0.069	-0.019	-0.086	-0.029	-0.052	0.013	-0.021	0.074	-0.020	-0.081

Table C.1.4.1 Unit Price Correlation Matrix Based on Cost

Activity	Temporary Access & Maintenance	Dewatering	Concrete Support	Unit Price	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.018	0.005	0.106	0.077	-0.118	-0.132	-0.097	-0.073	0.086	0.311	0.010
Field Supervision	0.028	-0.004	0.699	0.387	-0.058	-0.074	-0.102	-0.133	-0.030	-0.021	-0.069
Carpenter Foreman	-0.002	-0.001	0.044	-0.038	0.070	0.064	-0.002	-0.084	0.063	-0.015	-0.019
Master Mechanic & Maintenance Foreman	0.032	-0.003	-0.012	0.025	-0.130	-0.145	-0.127	-0.103	-0.025	0.081	-0.086
Fuel, Oil, Grease for Equipment	-0.019	0.011	-0.034	-0.021	-0.064	-0.071	-0.063	-0.104	-0.020	0.072	-0.029
Labor Shop Steward	0.038	-0.008	-0.006	0.068	-0.049	-0.057	-0.070	-0.092	-0.020	0.057	-0.052
Teamsters	-0.036	-0.006	0.026	-0.003	0.013	0.018	0.029	-0.041	0.100	0.003	0.013
Offsite Yard Crew	0.007	0.175	0.283	0.270	-0.042	-0.048	-0.041	0.222	0.066	0.038	-0.021
Survey Party	-0.006	-0.006	-0.010	-0.017	0.057	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	0.004	0.023	-0.018	-0.125	-0.080	-0.073	0.012	0.074	-0.028	-0.058	-0.020
Maintenance & Protection of Traffic	0.021	-0.010	-0.029	0.026	-0.120	-0.127	-0.088	-0.084	0.025	0.111	-0.081
Temporary Access & Maintenance	1.000	-0.005	-0.011	-0.020	0.105	0.095	-0.031	0.006	-0.073	-0.065	0.004
Dewatering	-0.005	1.000	-0.010	0.111	0.058	0.035	-0.100	0.131	-0.056	-0.048	-0.055
Crane Support	-0.011	-0.010	1.000	0.701	0.040	0.029	-0.041	-0.042	-0.043	-0.088	-0.083
Unit Price	-0.020	0.111	0.701	1.000	-0.051	-0.048	0.001	0.113	0.056	-0.004	-0.081
Average Temperature (F)	0.105	0.058	0.040	-0.051	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.095	0.035	0.029	-0.048	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.031	-0.100	-0.041	0.001	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.006	0.131	-0.042	0.113	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.073	-0.056	-0.043	0.056	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	-0.048	-0.088	-0.004	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	-0.055	-0.083	-0.081	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.1.4.2 Unit Price Correlation Matrix Based on Cost

	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.268	0.021	0.281	0.205	0.219	0.200	0.078	0.012	0.048	0.241
Field Supervision	0.268	1.000	-0.073	0.613	0.399	0.626	0.433	0.233	-0.009	0.098	0.609
Carpenter Foreman	0.021	-0.073	1.000	-0.185	0.017	-0.316	0.387	-0.052	0.030	0.089	-0.363
Master Mechanic & Maintenance Foreman	0.281	0.613	-0.185	1.000	0.628	0.913	0.554	0.081	-0.025	0.121	0.899
Fuel, Oil, Grease for Equipment	0.205	0.399	0.017	0.628	1.000	0.585	0.496	0.291	-0.028	0.119	0.572
Labor Shop Steward	0.219	0.626	-0.316	0.913	0.585	1.000	0.496	0.046	-0.011	0.057	0.957
Teamsters	0.200	0.433	0.387	0.554	0.496	0.496	1.000	0.000	0.022	0.345	0.437
Offsite Yard Crew	0.078	0.233	-0.052	0.081	0.291	0.046	0.000	1.000	-0.014	-0.002	0.058
Survey Party	0.012	-0.009	0.030	-0.025	-0.028	-0.011	0.022	-0.014	1.000	-0.003	0.026
Maintain Field Office	0.048	0.098	0.089	0.121	0.119	0.057	0.345	-0.002	-0.003	1.000	0.053
Maintenance & Protection of Traffic	0.241	0.609	-0.363	0.899	0.572	0.957	0.437	0.058	0.026	0.053	1.000
Temporary Access & Maintenance	0.018	0.028	-0.002	0.032	-0.019	0.038	-0.036	0.007	-0.006	0.004	0.021
Dewatering	0.005	-0.004	-0.001	-0.003	0.011	-0.008	-0.006	0.175	-0.006	0.023	-0.010
Crane Support	0.106	0.699	0.044	-0.012	-0.034	-0.006	0.026	0.283	-0.010	-0.018	-0.029
Cut-Off, Haul & Dispose Piles	-0.039	-0.057	-0.096	-0.046	-0.084	-0.005	-0.169	0.009	0.000	0.012	0.006
Average Temperature (F)	-0.118	-0.058	0.070	-0.130	-0.064	-0.049	0.013	-0.042	0.057	-0.080	-0.120
Average Dewpoint (F)	-0.132	-0.074	0.064	-0.145	-0.071	-0.057	0.018	-0.048	0.088	-0.073	-0.127
Average Humidity (%)	-0.097	-0.102	-0.002	-0.127	-0.063	-0.070	0.029	-0.041	0.187	0.012	-0.088
Average Pressure (IN)	-0.073	-0.133	-0.084	-0.103	-0.104	-0.092	-0.041	0.222	0.012	0.074	-0.084
Average Wind Speed (MPH)	0.086	-0.030	0.063	-0.025	-0.020	-0.020	0.100	0.066	0.344	-0.028	0.025
Maximum Gust Speed (MPH)	0.311	-0.021	-0.015	0.081	0.072	0.057	0.003	0.038	0.104	-0.058	0.111
Precipitation Sum (IN)	0.010	-0.069	-0.019	-0.086	-0.029	-0.052	0.013	-0.021	0.074	-0.020	-0.081

Table C.1.5.1 Cut-Off, Haul & Dispose Piles Correlation Matrix Based on Cost

	Temporary Access & Maintenance	Dewatering	Concrete Support	Cut-Off, Haul & Dispose Piles	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.018	0.005	0.106	-0.039	-0.118	-0.132	-0.097	-0.073	0.086	0.311	0.010
Field Supervision	0.028	-0.004	0.699	-0.057	-0.058	-0.074	-0.102	-0.133	-0.030	-0.021	-0.069
Carpenter Foreman	-0.002	-0.001	0.044	-0.096	0.070	0.064	-0.002	-0.084	0.063	-0.015	-0.019
Master Mechanic & Maintenance Foreman	0.032	-0.003	-0.012	-0.046	-0.130	-0.145	-0.127	-0.103	-0.025	0.081	-0.086
Fuel, Oil, Grease for Equipment	-0.019	0.011	-0.034	-0.084	-0.064	-0.071	-0.063	-0.104	-0.020	0.072	-0.029
Labor Shop Steward	0.038	-0.008	-0.006	-0.005	-0.049	-0.057	-0.070	-0.092	-0.020	0.057	-0.052
Teamsters	-0.036	-0.006	0.026	-0.169	0.013	0.018	0.029	-0.041	0.100	0.003	0.013
Offsite Yard Crew	0.007	0.175	0.283	0.009	-0.042	-0.048	-0.041	0.222	0.066	0.038	-0.021
Survey Party	-0.006	-0.006	-0.010	0.000	0.057	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	0.004	0.023	-0.018	0.012	-0.080	-0.073	0.012	0.074	-0.028	-0.058	-0.020
Maintenance & Protection of Traffic	0.021	-0.010	-0.029	0.006	-0.120	-0.127	-0.088	-0.084	0.025	0.111	-0.081
Temporary Access & Maintenance	1.000	-0.005	-0.011	0.005	0.105	0.095	-0.031	0.006	-0.073	-0.065	0.004
Dewatering	-0.005	1.000	-0.010	0.009	0.058	0.035	-0.100	0.131	-0.056	-0.048	-0.055
Crane Support	-0.011	-0.010	1.000	0.001	0.040	0.029	-0.041	-0.042	-0.043	-0.088	-0.083
Cut-Off, Haul & Dispose Piles	0.005	0.009	0.001	1.000	0.039	0.028	-0.052	-0.026	0.114	0.184	0.011
Average Temperature (F)	0.105	0.058	0.040	0.039	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.095	0.035	0.029	0.028	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.031	-0.100	-0.041	-0.052	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.006	0.131	-0.042	-0.026	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.073	-0.056	-0.043	0.114	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	-0.048	-0.088	0.184	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	-0.055	-0.083	0.011	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.1.5.2 Cut-Off, Haul & Dispose Piles Correlation Matrix Based on Cost

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.268	0.021	0.281	0.205	0.219	0.200	0.078	0.012	0.048	0.241
Field Supervision	0.268	1.000	-0.073	0.613	0.399	0.626	0.433	0.233	-0.009	0.098	0.609
Carpenter Foreman	0.021	-0.073	1.000	-0.185	0.017	-0.316	0.387	-0.052	0.030	0.089	-0.363
Master Mechanic & Maintenance Foreman	0.281	0.613	-0.185	1.000	0.628	0.913	0.554	0.081	-0.025	0.121	0.899
Fuel, Oil, Grease for Equipment	0.205	0.399	0.017	0.628	1.000	0.585	0.496	0.291	-0.028	0.119	0.572
Labor Shop Steward	0.219	0.626	-0.316	0.913	0.585	1.000		0.046	-0.011	0.057	0.957
Teamsters	0.200	0.433	0.387	0.554	0.496	0.496	1.000	0.000	0.022	0.345	0.437
Offsite Yard Crew	0.078	0.233	-0.052	0.081	0.291	0.046	0.000	1.000	-0.014	-0.002	0.058
Survey Party	0.012	-0.009	0.030	-0.025	-0.028	-0.011	0.022	-0.014	1.000	-0.003	0.026
Maintain Field Office	0.048	0.098	0.089	0.121	0.119	0.057	0.345	-0.002	-0.003	1.000	0.053
Maintenance & Protection of Traffic	0.241	0.609	-0.363	0.899	0.572	0.957	0.437	0.058	0.026	0.053	1.000
Temporary Access & Maintenance	0.018	0.028	-0.002	0.032	-0.019	0.038	-0.036	0.007	-0.006	0.004	0.021
Dewatering	0.005	-0.004	-0.001	-0.003	0.011	-0.008	-0.006	0.175	-0.006	0.023	-0.010
Crane Support	0.106	0.699	0.044	-0.012	-0.034	-0.006	0.026	0.283	-0.010	-0.018	-0.029
Concrete Demolition	-0.047	-0.444	0.016	0.064	0.052	0.014	0.026	-0.152	0.004	0.078	0.040
Average Temperature (F)	-0.118	-0.058	0.070	-0.130	-0.064	-0.049	0.013	-0.042	0.057	-0.080	-0.120
Average Dewpoint (F)	-0.132	-0.074	0.064	-0.145	-0.071	-0.057	0.018	-0.048	0.088	-0.073	-0.127
Average Humidity (%)	-0.097	-0.102	-0.002	-0.127	-0.063	-0.070	0.029	-0.041	0.187	0.012	-0.088
Average Pressure (IN)	-0.073	-0.133	-0.084	-0.103	-0.104	-0.092	-0.041	0.222	0.012	0.074	-0.084
Average Wind Speed (MPH)	0.086	-0.030	0.063	-0.025	-0.020	-0.020	0.100	0.066	0.344	-0.028	0.025
Maximum Gust Speed (MPH)	0.311	-0.021	-0.015	0.081	0.072	0.057	0.003	0.038	0.104	-0.058	0.111
Precipitation Sum (IN)	0.010	-0.069	-0.019	-0.086	-0.029	-0.052	0.013	-0.021	0.074	-0.020	-0.081

Table C.1.6.1 Concrete Demolition Correlation Matrix Based on Cost

Activity	Temporary Access & Maintenance	Dewatering	Crane Support	Concrete Demolition	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.018	0.005	0.106	-0.047	-0.118	-0.132	-0.097	-0.073	0.086	0.311	0.010
Field Supervision	0.028	-0.004	0.699	-0.444	-0.058	-0.074	-0.102	-0.133	-0.030	-0.021	-0.069
Carpenter Foreman	-0.002	-0.001	0.044	0.016	0.070	0.064	-0.002	-0.084	0.063	-0.015	-0.019
Master Mechanic & Maintenance Foreman	0.032	-0.003	-0.012	0.064	-0.130	-0.145	-0.127	-0.103	-0.025	0.081	-0.086
Fuel, Oil, Grease for Equipment	-0.019	0.011	-0.034	0.052	-0.064	-0.071	-0.063	-0.104	-0.020	0.072	-0.029
Labor Shop Steward	0.038	-0.008	-0.006	0.014	-0.049	-0.057	-0.070	-0.092	-0.020	0.057	-0.052
Teamsters	-0.036	-0.006	0.026	0.026	0.013	0.018	0.029	-0.041	0.100	0.003	0.013
Offsite Yard Crew	0.007	0.175	0.283	-0.152	-0.042	-0.048	-0.041	0.222	0.066	0.038	-0.021
Survey Party	-0.006	-0.006	-0.010	0.004	0.057	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	0.004	0.023	-0.018	0.078	-0.080	-0.073	0.012	0.074	-0.028	-0.058	-0.020
Maintenance & Protection of Traffic	0.021	-0.010	-0.029	0.040	-0.120	-0.127	-0.088	-0.084	0.025	0.111	-0.081
Temporary Access & Maintenance	1.000	-0.005	-0.011	0.003	0.105	0.095	-0.031	0.006	-0.073	-0.065	0.004
Dewatering	-0.005	1.000	-0.010	-0.004	0.058	0.035	-0.100	0.131	-0.056	-0.048	-0.055
Crane Support	-0.011	-0.010	1.000	-0.595	0.040	0.029	-0.041	-0.042	-0.043	-0.088	-0.083
Concrete Demolition	0.003	-0.004	-0.595	1.000	-0.046	-0.040	0.025	0.108	0.066	0.038	0.061
Average Temperature (F)	0.105	0.058	0.040	-0.046	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.095	0.035	0.029	-0.040	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.031	-0.100	-0.041	0.025	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.006	0.131	-0.042	0.108	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.073	-0.056	-0.043	0.066	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	-0.048	-0.088	0.038	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	-0.055	-0.083	0.061	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.1.6.2 Concrete Demolition Correlation Matrix Based on Cost

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.268	0.021	0.281	0.205	0.219	0.200	0.078	0.012	0.048	0.241
Field Supervision	0.268	1.000	-0.073	0.613	0.399	0.626	0.433	0.233	-0.009	0.098	0.609
Carpenter Foreman	0.021	-0.073	1.000	-0.185	0.017	-0.316	0.387	-0.052	0.030	0.089	-0.363
Master Mechanic & Maintenance Foreman	0.281	0.613	-0.185	1.000	0.628	0.913	0.554	0.081	-0.025	0.121	0.899
Fuel, Oil, Grease for Equipment	0.205	0.399	0.017	0.628	1.000	0.585	0.496	0.291	-0.028	0.119	0.572
Labor Shop Steward	0.219	0.626	-0.316	0.913	0.585	1.000	0.496	0.046	-0.011	0.057	0.957
Teamsters	0.200	0.433	0.387	0.554	0.496	0.496	1.000	0.000	0.022	0.345	0.437
Offsite Yard Crew	0.078	0.233	-0.052	0.081	0.291	0.046	0.000	1.000	-0.014	-0.002	0.058
Survey Party	0.012	-0.009	0.030	-0.025	-0.028	-0.011	0.022	-0.014	1.000	-0.003	0.026
Maintain Field Office	0.048	0.098	0.089	0.121	0.119	0.057	0.345	-0.002	-0.003	1.000	0.053
Maintenance & Protection of Traffic	0.241	0.609	-0.363	0.899	0.572	0.957	0.437	0.058	0.026	0.053	1.000
Temporary Access & Maintenance	0.018	0.028	-0.002	0.032	-0.019	0.038	-0.036	0.007	-0.006	0.004	0.021
Dewatering	0.005	-0.004	-0.001	-0.003	0.011	-0.008	-0.006	0.175	-0.006	0.023	-0.010
Crane Support	0.106	0.699	0.044	-0.012	-0.034	-0.006	0.026	0.283	-0.010	-0.018	-0.029
F+I Structural Steel	-0.016	0.016	-0.023	-0.009	-0.083	0.045	-0.046	0.045	0.016	-0.011	0.027
F+I Miscellaneous Metal	0.029	0.031	0.229	-0.030	0.063	0.017	0.134	0.129	-0.002	0.003	-0.011
Average Temperature (F)	-0.118	-0.058	0.070	-0.130	-0.064	-0.049	0.013	-0.042	0.057	-0.080	-0.120
Average Dewpoint (F)	-0.132	-0.074	0.064	-0.145	-0.071	-0.057	0.018	-0.048	0.088	-0.073	-0.127
Average Humidity (%)	-0.097	-0.102	-0.002	-0.127	-0.063	-0.070	0.029	-0.041	0.187	0.012	-0.088
Average Pressure (IN)	-0.073	-0.133	-0.084	-0.103	-0.104	-0.092	-0.041	0.222	0.012	0.074	-0.084
Average Wind Speed (MPH)	0.086	-0.030	0.063	-0.025	-0.020	-0.020	0.100	0.066	0.344	-0.028	0.025
Maximum Gust Speed (MPH)	0.311	-0.021	-0.015	0.081	0.072	0.057	0.003	0.038	0.104	-0.058	0.111
Precipitation Sum (IN)	0.010	-0.069	-0.019	-0.086	-0.029	-0.052	0.013	-0.021	0.074	-0.020	-0.081

Table C.1.7.1 Metal Correlation Matrix Based on Cost

Activity	Temporary Access & Maintenance	Dewatering	Crane Support	F&I Structural Steel	F&I Miscellaneous Metal	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.018	0.005	0.106	-0.016	0.029	-0.118	-0.132	-0.097	-0.073	0.086	0.311	0.010
Field Supervision	0.028	-0.004	0.699	0.016	0.031	-0.058	-0.074	-0.102	-0.133	-0.030	-0.021	-0.069
Carpenter Foreman	-0.002	-0.001	0.044	-0.023	0.229	0.070	0.064	-0.002	-0.084	0.063	-0.015	-0.019
Master Mechanic & Maintenance Foreman	0.032	-0.003	-0.012	-0.009	-0.030	-0.130	-0.145	-0.127	-0.103	-0.025	0.081	-0.086
Fuel, Oil, Grease for Equipment	-0.019	0.011	-0.034	-0.083	0.063	-0.064	-0.071	-0.063	-0.104	-0.020	0.072	-0.029
Labor Shop Steward	0.038	-0.008	-0.006	0.045	0.017	-0.049	-0.057	-0.070	-0.092	-0.020	0.057	-0.052
Teamsters	-0.036	-0.006	0.026	-0.046	0.134	0.013	0.018	0.029	-0.041	0.100	0.003	0.013
Offsite Yard Crew	0.007	0.175	0.283	0.045	0.129	-0.042	-0.048	-0.041	0.222	0.066	0.038	-0.021
Survey Party	-0.006	-0.006	-0.010	0.016	-0.002	0.057	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	0.004	0.023	-0.018	-0.011	0.003	-0.080	-0.073	0.012	0.074	-0.028	-0.058	-0.020
Maintenance & Protection of Traffic	0.021	-0.010	-0.029	0.027	-0.011	-0.120	-0.127	-0.088	-0.084	0.025	0.111	-0.081
Temporary Access & Maintenance	1.000	-0.005	-0.011	0.004	-0.011	0.105	0.095	-0.031	0.006	-0.073	-0.065	0.004
Dewatering	-0.005	1.000	-0.010	0.026	0.642	0.058	0.035	-0.100	0.131	-0.056	-0.048	-0.055
Crane Support	-0.011	-0.010	1.000	0.048	-0.076	0.040	0.029	-0.041	-0.042	-0.043	-0.088	-0.083
F+I Structural Steel	0.004	0.026	0.048	1.000	-0.049	0.009	0.005	-0.016	-0.007	0.181	0.135	0.007
F+I Misc Metal	-0.011	0.642	-0.076	-0.049	1.000	0.029	0.012	-0.076	0.097	-0.032	-0.017	0.022
Average Temperature (F)	0.105	0.058	0.040	0.009	0.029	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.095	0.035	0.029	0.005	0.012	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.031	-0.100	-0.041	-0.016	-0.076	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.006	0.131	-0.042	-0.007	0.097	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.073	-0.056	-0.043	0.181	-0.032	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	-0.048	-0.088	0.135	-0.017	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	-0.055	-0.083	0.007	0.022	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.1.7.2 Metal Correlation Matrix Based on Cost

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.268	0.021	0.281	0.205	0.219	0.200	0.078	0.012	0.048	0.241
Field Supervision	0.268	1.000	-0.073	0.613	0.399	0.626	0.433	0.233	-0.009	0.098	0.609
Carpenter Foreman	0.021	-0.073	1.000	-0.185	0.017	-0.316	0.387	-0.052	0.030	0.089	-0.363
Master Mechanic & Maintenance Foreman	0.281	0.613	-0.185	1.000	0.628	0.913	0.554	0.081	-0.025	0.121	0.899
Fuel, Oil, Grease for Equipment	0.205	0.399	0.017	0.628	1.000	0.585	0.496	0.291	-0.028	0.119	0.572
Labor Shop Steward	0.219	0.626	-0.316	0.913	0.585	1.000	0.496	0.046	-0.011	0.057	0.957
Teamsters	0.200	0.433	0.387	0.554	0.496	0.496	1.000	0.000	0.022	0.345	0.437
Offsite Yard Crew	0.078	0.233	-0.052	0.081	0.291	0.046	0.000	1.000	-0.014	-0.002	0.058
Survey Party	0.012	-0.009	0.030	-0.025	-0.028	-0.011	0.022	-0.014	1.000	-0.003	0.026
Maintain Field Office	0.048	0.098	0.089	0.121	0.119	0.057	0.345	-0.002	-0.003	1.000	0.053
Maintenance & Protection of Traffic	0.241	0.609	-0.363	0.899	0.572	0.957	0.437	0.058	0.026	0.053	1.000
Temporary Access & Maintenance	0.018	0.028	-0.002	0.032	-0.019	0.038	-0.036	0.007	-0.006	0.004	0.021
Dewatering	0.005	-0.004	-0.001	-0.003	0.011	-0.008	-0.006	0.175	-0.006	0.023	-0.010
Crane Support	0.106	0.699	0.044	-0.012	-0.034	-0.006	0.026	0.283	-0.010	-0.018	-0.029
Furnish & Install Furnish & Install Pipes & Fittings	-0.008	0.005	0.039	0.026	0.002	0.007	0.003	-0.167	0.010	0.144	0.013
Mechanical	0.007	0.032	-0.274	0.116	0.022	0.093	-0.019	-0.088	-0.002	0.017	0.119
Average Temperature (F)	-0.118	-0.058	0.070	-0.130	-0.064	-0.049	0.013	-0.042	0.057	-0.080	-0.120
Average Dewpoint (F)	-0.132	-0.074	0.064	-0.145	-0.071	-0.057	0.018	-0.048	0.088	-0.073	-0.127
Average Humidity (%)	-0.097	-0.102	-0.002	-0.127	-0.063	-0.070	0.029	-0.041	0.187	0.012	-0.088
Average Pressure (IN)	-0.073	-0.133	-0.084	-0.103	-0.104	-0.092	-0.041	0.222	0.012	0.074	-0.084
Average Wind Speed (MPH)	0.086	-0.030	0.063	-0.025	-0.020	-0.020	0.100	0.066	0.344	-0.028	0.025
Maximum Gust Speed (MPH)	0.311	-0.021	-0.015	0.081	0.072	0.057	0.003	0.038	0.104	-0.058	0.111
Precipitation Sum (IN)	0.010	-0.069	-0.019	-0.086	-0.029	-0.052	0.013	-0.021	0.074	-0.020	-0.081

Table C.1.8.1 Mechanical Correlation Matrix Based on Cost

Activity	Temporary Access & Maintenance	Dewatering	Crane Support	Furnish & Install Pipes & Fittings	Mechanical	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.018	0.005	0.106	-0.008	0.007	-0.118	-0.132	-0.097	-0.073	0.086	0.311	0.010
Field Supervision	0.028	-0.004	0.699	0.005	0.032	-0.058	-0.074	-0.102	-0.133	-0.030	-0.021	-0.069
Carpenter Foreman	-0.002	-0.001	0.044	0.039	-0.274	0.070	0.064	-0.002	-0.084	0.063	-0.015	-0.019
Master Mechanic & Maintenance Foreman	0.032	-0.003	-0.012	0.026	0.116	-0.130	-0.145	-0.127	-0.103	-0.025	0.081	-0.086
Fuel, Oil, Grease for Equipment	-0.019	0.011	-0.034	0.002	0.022	-0.064	-0.071	-0.063	-0.104	-0.020	0.072	-0.029
Labor Shop Steward	0.038	-0.008	-0.006	0.007	0.093	-0.049	-0.057	-0.070	-0.092	-0.020	0.057	-0.052
Teamsters	-0.036	-0.006	0.026	0.003	-0.019	0.013	0.018	0.029	-0.041	0.100	0.003	0.013
Offsite Yard Crew	0.007	0.175	0.283	-0.167	-0.088	-0.042	-0.048	-0.041	0.222	0.066	0.038	-0.021
Survey Party	-0.006	-0.006	-0.010	0.010	-0.002	0.057	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	0.004	0.023	-0.018	0.144	0.017	-0.080	-0.073	0.012	0.074	-0.028	-0.058	-0.020
Maintenance & Protection of Traffic	0.021	-0.010	-0.029	0.013	0.119	-0.120	-0.127	-0.088	-0.084	0.025	0.111	-0.081
Temporary Access & Maintenance	1.000	-0.005	-0.011	0.006	0.011	0.105	0.095	-0.031	0.006	-0.073	-0.065	0.004
Dewatering	-0.005	1.000	-0.010	-0.397	-0.595	0.058	0.035	-0.100	0.131	-0.056	-0.048	-0.055
Crane Support	-0.011	-0.010	1.000	-0.255	-0.006	0.040	0.029	-0.041	-0.042	-0.043	-0.088	-0.083
Furnish & Install Pipes & Fittings	0.006	-0.397	-0.255	1.000	0.232	0.020	0.022	0.010	-0.115	0.004	-0.006	0.064
Mechanical	0.011	-0.595	-0.006	0.232	1.000	-0.158	-0.149	-0.003	-0.130	0.106	0.087	0.066
Average Temperature (F)	0.105	0.058	0.040	0.020	-0.158	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.095	0.035	0.029	0.022	-0.149	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.031	-0.100	-0.041	0.010	-0.003	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.006	0.131	-0.042	-0.115	-0.130	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.073	-0.056	-0.043	0.004	0.106	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	-0.048	-0.088	-0.006	0.087	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	-0.055	-0.083	0.064	0.066	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.1.8.2 Mechanical Correlation Matrix Based on Cost

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.268	0.021	0.281	0.205	0.219	0.200	0.078	0.012	0.048	0.241
Field Supervision	0.268	1.000	-0.073	0.613	0.399	0.626	0.433	0.233	-0.009	0.098	0.609
Carpenter Foreman	0.021	-0.073	1.000	-0.185	0.017	-0.316	0.387	-0.052	0.030	0.089	-0.363
Master Mechanic & Maintenance Foreman	0.281	0.613	-0.185	1.000	0.628	0.913	0.554	0.081	-0.025	0.121	0.899
Fuel, Oil, Grease for Equipment	0.205	0.399	0.017	0.628	1.000	0.585	0.496	0.291	-0.028	0.119	0.572
Labor Shop Steward	0.219	0.626	-0.316	0.913	0.585	1.000	0.496	0.046	-0.011	0.057	0.957
Teamsters	0.200	0.433	0.387	0.554	0.496	0.496	1.000	0.000	0.022	0.345	0.437
Offsite Yard Crew	0.078	0.233	-0.052	0.081	0.291	0.046	0.000	1.000	-0.014	-0.002	0.058
Survey Party	0.012	-0.009	0.030	-0.025	-0.028	-0.011	0.022	-0.014	1.000	-0.003	0.026
Maintain Field Office	0.048	0.098	0.089	0.121	0.119	0.057	0.345	-0.002	-0.003	1.000	0.053
Maintenance & Protection of Traffic	0.241	0.609	-0.363	0.899	0.572	0.957	0.437	0.058	0.026	0.053	1.000
Temporary Access & Maintenance	0.018	0.028	-0.002	0.032	-0.019	0.038	-0.036	0.007	-0.006	0.004	0.021
Dewatering	0.005	-0.004	-0.001	-0.003	0.011	-0.008	-0.006	0.175	-0.006	0.023	-0.010
Concrete Support	0.106	0.699	0.044	-0.012	-0.034	-0.006	0.026	0.283	-0.010	-0.018	-0.029
Thermal & Moist Protection	-0.005	-0.042	-0.010	-0.043	-0.045	0.020	-0.020	-0.028	-0.015	-0.051	-0.028
Doors & Windows	-0.017	0.011	-0.150	-0.005	0.026	-0.051	-0.122	-0.018	0.004	0.036	0.013
Average Temperature (F)	-0.118	-0.058	0.070	-0.130	-0.064	-0.049	0.013	-0.042	0.057	-0.080	-0.120
Average Dewpoint (F)	-0.132	-0.074	0.064	-0.145	-0.071	-0.057	0.018	-0.048	0.088	-0.073	-0.127
Average Humidity (%)	-0.097	-0.102	-0.002	-0.127	-0.063	-0.070	0.029	-0.041	0.187	0.012	-0.088
Average Pressure (IN)	-0.073	-0.133	-0.084	-0.103	-0.104	-0.092	-0.041	0.222	0.012	0.074	-0.084
Average Wind Speed (MPH)	0.086	-0.030	0.063	-0.025	-0.020	-0.020	0.100	0.066	0.344	-0.028	0.025
Maximum Gust Speed (MPH)	0.311	-0.021	-0.015	0.081	0.072	0.057	0.003	0.038	0.104	-0.058	0.111
Precipitation Sum (IN)	0.010	-0.069	-0.019	-0.086	-0.029	-0.052	0.013	-0.021	0.074	-0.020	-0.081

Table C.1.9.1 Architectural Correlation Matrix Based on Cost

Activity	Temporary Access & Maintenance	Dewatering	Concrete Support	Thermal & Moist Protection	Doors & Windows	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.018	0.005	0.106	-0.005	-0.017	-0.118	-0.132	-0.097	-0.073	0.086	0.311	0.010
Field Supervision	0.028	-0.004	0.699	-0.042	0.011	-0.058	-0.074	-0.102	-0.133	-0.030	-0.021	-0.069
Carpenter Foreman	-0.002	-0.001	0.044	-0.010	-0.150	0.070	0.064	-0.002	-0.084	0.063	-0.015	-0.019
Master Mechanic & Maintenance Foreman	0.032	-0.003	-0.012	-0.043	-0.005	-0.130	-0.145	-0.127	-0.103	-0.025	0.081	-0.086
Fuel, Oil, Grease for Equipment	-0.019	0.011	-0.034	-0.045	0.026	-0.064	-0.071	-0.063	-0.104	-0.020	0.072	-0.029
Labor Shop Steward	0.038	-0.008	-0.006	0.020	-0.051	-0.049	-0.057	-0.070	-0.092	-0.020	0.057	-0.052
Teamsters	-0.036	-0.006	0.026	-0.020	-0.122	0.013	0.018	0.029	-0.041	0.100	0.003	0.013
Offsite Yard Crew	0.007	0.175	0.283	-0.028	-0.018	-0.042	-0.048	-0.041	0.222	0.066	0.038	-0.021
Survey Party	-0.006	-0.006	-0.010	-0.015	0.004	0.057	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	0.004	0.023	-0.018	-0.051	0.036	-0.080	-0.073	0.012	0.074	-0.028	-0.058	-0.020
Protection of Traffic	0.021	-0.010	-0.029	-0.028	0.013	-0.120	-0.127	-0.088	-0.084	0.025	0.111	-0.081
Temporary Access & Maintenance	1.000	-0.005	-0.011	-0.032	0.048	0.105	0.095	-0.031	0.006	-0.073	-0.065	0.004
Dewatering	-0.005	1.000	-0.010	-0.081	-0.021	0.058	0.035	-0.100	0.131	-0.056	-0.048	-0.055
Crane Support	-0.011	-0.010	1.000	-0.018	0.015	0.040	0.029	-0.041	-0.042	-0.043	-0.088	-0.083
Thermal & Moist Protection	-0.032	-0.081	-0.018	1.000	-0.375	-0.045	-0.043	0.004	0.166	0.062	-0.090	-0.033
Doors & Windows	0.048	-0.021	0.015	-0.375	1.000	0.059	0.056	0.006	-0.171	-0.310	-0.111	0.026
Average Temperature (F)	0.105	0.058	0.040	-0.045	0.059	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.095	0.035	0.029	-0.043	0.056	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.031	-0.100	-0.041	0.004	0.006	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.006	0.131	-0.042	0.166	-0.171	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.073	-0.056	-0.043	0.062	-0.310	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	-0.048	-0.088	-0.090	-0.111	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	-0.055	-0.083	-0.033	0.026	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.1.9.2 Architectural Correlation Matrix Based on Cost

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.484	0.129	0.671	0.437	0.569	0.570	0.197	0.008	-0.088	0.571
Field Supervision	0.484	1.000	0.023	0.343	0.170	0.343	0.294	0.279	-0.008	-0.059	0.320
Carpenter Foreman	0.129	0.023	1.000	-0.100	0.089	-0.292	0.410	-0.054	0.029	-0.098	-0.345
Master Mechanic & Maintenance Foreman	0.671	0.343	-0.100	1.000	0.514	0.868	0.584	0.091	-0.029	-0.062	0.845
Fuel, Oil, Grease for Equipment	0.437	0.170	0.089	0.514	1.000	0.452	0.454	0.407	-0.029	-0.041	0.427
Labor Shop Steward	0.569	0.343	-0.292	0.868	0.452	1.000	0.504	0.047	-0.009	-0.012	0.942
Teamsters	0.570	0.294	0.410	0.584	0.454	0.504	1.000	0.002	0.023	-0.180	0.431
Offsite Yard Crew	0.197	0.279	-0.054	0.091	0.407	0.047	0.002	1.000	-0.014	0.114	0.061
Survey Party	0.008	-0.008	0.029	-0.029	-0.029	-0.009	0.023	-0.014	1.000	-0.023	0.037
Maintain Field Office	-0.088	-0.059	-0.098	-0.062	-0.041	-0.012	-0.180	0.114	-0.023	1.000	-0.020
Maintenance & Protection of Traffic	0.571	0.320	-0.345	0.845	0.427	0.942	0.431	0.061	0.037	-0.020	1.000
Temporary Access & Maintenance	0.005	0.002	0.005	0.015	-0.033	0.008	-0.048	0.026	-0.008	-0.021	-0.007
Dewatering	-0.002	0.005	-0.014	0.009	-0.012	0.000	-0.007	-0.172	0.007	-0.787	0.013
Concrete Support	0.064	0.015	0.090	-0.013	0.002	-0.026	0.046	0.087	-0.009	-0.076	-0.048
Furnish Concrete	-0.277	-0.163	0.190	-0.422	-0.213	-0.474	-0.201	0.102	0.000	0.680	-0.479
Install Form	-0.021	-0.005	-0.019	0.006	-0.009	0.031	-0.023	-0.021	-0.005	0.046	0.004
Install Rebar	-0.015	-0.006	-0.098	0.021	-0.046	0.014	-0.068	0.022	-0.011	-0.018	0.007
Pour Concrete	0.028	0.037	-0.085	0.091	0.061	0.137	0.179	0.013	0.001	0.064	0.123
Finish Concrete	0.033	0.039	0.041	-0.014	0.010	0.035	0.053	-0.013	-0.002	0.066	0.013
Furnish & Install Grout	-0.092	-0.029	-0.134	-0.055	-0.142	-0.022	-0.076	-0.026	-0.009	0.019	-0.010
Average Temperature (F)	-0.189	-0.006	0.081	-0.097	-0.061	-0.040	0.013	-0.042	0.058	0.158	-0.118
Average Dewpoint (F)	-0.205	-0.020	0.076	-0.113	-0.068	-0.047	0.018	-0.047	0.088	0.121	-0.124
Average Humidity (%)	-0.136	-0.076	0.006	-0.128	-0.057	-0.065	0.031	-0.041	0.187	-0.140	-0.083
Average Pressure (IN)	-0.095	-0.126	-0.083	-0.110	-0.064	-0.098	-0.035	0.219	0.012	0.076	-0.084
Average Wind Speed (MPH)	0.101	-0.049	0.051	-0.051	-0.015	-0.026	0.085	0.065	0.344	-0.103	0.030
Maximum Gust Speed (MPH)	0.223	-0.068	-0.017	0.060	0.062	0.052	-0.007	0.036	0.104	-0.067	0.110
Precipitation Sum (IN)	-0.049	-0.059	-0.013	-0.097	-0.022	-0.050	0.017	-0.021	0.074	-0.080	-0.086

Table C.2.1.1 Concrete Correlation Matrix Based on Time

Activity	Temporary Access & Maintenance	Dewatering	Concrete Support	Furnish Concrete	Install Form	Install Rebar	Place Concrete	Finish Concrete	Furnish & Install Grout	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.005	-0.002	0.064	-0.277	-0.021	-0.015	0.028	0.033	-0.092	-0.189	-0.205	-0.136	-0.095	0.101	0.223	-0.049
Field Supervision	0.002	0.005	0.015	-0.163	-0.005	-0.006	0.037	0.039	-0.029	-0.006	-0.020	-0.076	-0.126	-0.049	-0.068	-0.059
Carpenter Foreman Master Mechanic & Maintenance Foreman	0.005	-0.014	0.090	0.190	-0.019	-0.098	-0.085	0.041	-0.134	0.081	0.076	0.006	-0.083	0.051	-0.017	-0.013
	0.015	0.009	-0.013	-0.422	0.006	0.021	0.091	-0.014	-0.055	-0.097	-0.113	-0.128	-0.110	-0.051	0.060	-0.097
Fuel, Oil, Grease for Equipment	-0.033	-0.012	0.002	-0.213	-0.009	-0.046	0.061	0.010	-0.142	-0.061	-0.068	-0.057	-0.064	-0.015	0.062	-0.022
Labor Shop Steward	0.008	0.000	-0.026	-0.474	0.031	0.014	0.137	0.035	-0.022	-0.040	-0.047	-0.065	-0.098	-0.026	0.052	-0.050
Teamsters	-0.048	-0.007	0.046	-0.201	-0.023	-0.068	0.179	0.053	-0.076	0.013	0.018	0.031	-0.035	0.085	-0.007	0.017
Offsite Yard Crew	0.026	-0.172	0.087	0.102	-0.021	0.022	0.013	-0.013	-0.026	-0.042	-0.047	-0.041	0.219	0.065	0.036	-0.021
Survey Party	-0.008	0.007	-0.009	0.000	-0.005	-0.011	0.001	-0.002	-0.009	0.058	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	-0.021	-0.787	-0.076	0.680	0.046	-0.018	0.064	0.066	0.019	0.158	0.121	-0.140	0.076	-0.103	-0.067	-0.080
Maintenance & Protection of Traffic	-0.007	0.013	-0.048	-0.479	0.004	0.007	0.123	0.013	-0.010	-0.118	-0.124	-0.083	-0.084	0.030	0.110	-0.086
Temporary Access & Maintenance	1.000	0.008	-0.010	-0.007	-0.021	0.962	-0.002	-0.539	-0.007	0.110	0.100	-0.027	0.017	-0.064	-0.065	0.004
Dewatering	0.008	1.000	0.008	-0.861	-0.003	0.005	-0.012	-0.016	0.007	-0.071	-0.048	0.098	-0.139	0.057	0.048	0.056
Concrete Support	-0.010	0.008	1.000	-0.068	-0.004	0.016	0.005	0.062	0.001	0.001	0.003	0.018	0.128	0.031	0.026	-0.087
Furnish Concrete	-0.007	-0.861	-0.068	1.000	0.000	-0.010	-0.049	0.014	0.004	0.134	0.113	-0.062	0.130	-0.075	-0.097	-0.023
Install Form	-0.021	-0.003	-0.004	0.000	1.000	-0.078	-0.001	0.025	0.291	0.107	0.111	0.053	-0.090	-0.006	0.060	-0.024
Install Rebar	0.962	0.005	0.016	-0.010	-0.078	1.000	0.005	-0.504	-0.018	0.084	0.077	-0.018	0.004	-0.048	-0.075	0.012
Pour Concrete	-0.002	-0.012	0.005	-0.049	-0.001	0.005	1.000	0.005	0.011	0.129	0.138	0.086	0.028	-0.004	-0.012	-0.021
Finish Concrete	-0.539	-0.016	0.062	0.014	0.025	-0.504	0.005	1.000	-0.098	-0.174	-0.176	-0.048	-0.004	0.023	-0.004	0.022
Furnish & Install Grout	-0.007	0.007	0.001	0.004	0.291	-0.018	0.011	-0.098	1.000	0.133	0.144	0.109	-0.119	0.058	-0.026	0.036
Average Temperature (F)	0.110	-0.071	0.001	0.134	0.107	0.084	0.129	-0.174	0.133	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.100	-0.048	0.003	0.113	0.111	0.077	0.138	-0.176	0.144	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.027	0.098	0.018	-0.062	0.053	-0.018	0.086	-0.048	0.109	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.017	-0.139	0.128	0.130	-0.090	0.004	0.028	-0.004	-0.119	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.064	0.057	0.031	-0.075	-0.006	-0.048	-0.004	0.023	0.058	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	0.048	0.026	-0.097	0.060	-0.075	-0.012	-0.004	-0.026	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	0.056	-0.087	-0.023	-0.024	0.012	-0.021	0.022	0.036	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.2.1.2 Concrete Correlation Matrix Based on Time

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.484	0.129	0.671	0.437	0.569	0.570	0.197	0.008	-0.088	0.571
Field Supervision	0.484	1.000	0.023	0.343	0.170	0.343	0.294	0.279	-0.008	-0.059	0.320
Carpenter Foreman	0.129	0.023	1.000	-0.100	0.089	-0.292	0.410	-0.054	0.029	-0.098	-0.345
Master Mechanic & Maintenance Foreman	0.671	0.343	-0.100	1.000	0.514	0.868	0.584	0.091	-0.029	-0.062	0.845
Fuel, Oil, Grease for Equipment	0.437	0.170	0.089	0.514	1.000	0.452	0.454	0.407	-0.029	-0.041	0.427
Labor Shop Steward	0.569	0.343	-0.292	0.868	0.452	1.000	0.504	0.047	-0.009	-0.012	0.942
Teamsters	0.570	0.294	0.410	0.584	0.454	0.504	1.000	0.002	0.023	-0.180	0.431
Offsite Yard Crew	0.197	0.279	-0.054	0.091	0.407	0.047	0.002	1.000	-0.014	0.114	0.061
Survey Party	0.008	-0.008	0.029	-0.029	-0.029	-0.009	0.023	-0.014	1.000	-0.023	0.037
Maintain Field Office	-0.088	-0.059	-0.098	-0.062	-0.041	-0.012	-0.180	0.114	-0.023	1.000	-0.020
Maintenance & Protection of Traffic	0.571	0.320	-0.345	0.845	0.427	0.942	0.431	0.061	0.037	-0.020	1.000
Temporary Access & Maintenance	0.005	0.002	0.005	0.015	-0.033	0.008	-0.048	0.026	-0.008	-0.021	-0.007
SOE	-0.022	-0.138	-0.010	0.016	0.046	-0.024	0.060	-0.007	-0.001	0.137	-0.008
Dewatering	-0.002	0.005	-0.014	0.009	-0.012	0.000	-0.007	-0.172	0.007	-0.787	0.013
Crane Support	0.064	0.015	0.090	-0.013	0.002	-0.026	0.046	0.087	-0.009	-0.076	-0.048
Excavation	-0.002	0.019	-0.039	0.227	0.032	-0.006	-0.023	0.009	0.006	0.013	0.018
Fills & Backfills	-0.074	0.070	-0.151	-0.015	-0.077	0.033	-0.121	0.006	-0.004	-0.055	0.039
Average Temperature (F)	-0.189	-0.006	0.081	-0.097	-0.061	-0.040	0.013	-0.042	0.058	0.158	-0.118
Average Dewpoint (F)	-0.205	-0.020	0.076	-0.113	-0.068	-0.047	0.018	-0.047	0.088	0.121	-0.124
Average Humidity (%)	-0.136	-0.076	0.006	-0.128	-0.057	-0.065	0.031	-0.041	0.187	-0.140	-0.083
Average Pressure (IN)	-0.095	-0.126	-0.083	-0.110	-0.064	-0.098	-0.035	0.219	0.012	0.076	-0.084
Average Wind Speed (MPH)	0.101	-0.049	0.051	-0.051	-0.015	-0.026	0.085	0.065	0.344	-0.103	0.030
Maximum Gust Speed (MPH)	0.223	-0.068	-0.017	0.060	0.062	0.052	-0.007	0.036	0.104	-0.067	0.110
Precipitation Sum (IN)	-0.049	-0.059	-0.013	-0.097	-0.022	-0.050	0.017	-0.021	0.074	-0.080	-0.086

Table C.2.2.1. Excavation Correlation Matrix Based on Time

Activity	Temporary Access & Maintenance	SOE	Dewatering	Crane Support	Excavation	Fills & Backfills	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.005	-0.022	-0.002	0.064	-0.002	-0.074	-0.189	-0.205	-0.136	-0.095	0.101	0.223	-0.049
Field Supervision	0.002	-0.138	0.005	0.015	0.019	0.070	-0.006	-0.020	-0.076	-0.126	-0.049	-0.068	-0.059
Carpenter Foreman	0.005	-0.010	-0.014	0.090	-0.039	-0.151	0.081	0.076	0.006	-0.083	0.051	-0.017	-0.013
Master Mechanic & Maintenance Foreman	0.015	0.016	0.009	-0.013	0.227	-0.015	-0.097	-0.113	-0.128	-0.110	-0.051	0.060	-0.097
Fuel, Oil, Grease for Equipment	-0.033	0.046	-0.012	0.002	0.032	-0.077	-0.061	-0.068	-0.057	-0.064	-0.015	0.062	-0.022
Labor Shop Steward	0.008	-0.024	0.000	-0.026	-0.006	0.033	-0.040	-0.047	-0.065	-0.098	-0.026	0.052	-0.050
Teamsters	-0.048	0.060	-0.007	0.046	-0.023	-0.121	0.013	0.018	0.031	-0.035	0.085	-0.007	0.017
Offsite Yard Crew	0.026	-0.007	-0.172	0.087	0.009	0.006	-0.042	-0.047	-0.041	0.219	0.065	0.036	-0.021
Survey Party	-0.008	-0.001	0.007	-0.009	0.006	-0.004	0.058	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	-0.021	0.137	-0.787	-0.076	0.013	-0.055	0.158	0.121	-0.140	0.076	-0.103	-0.067	-0.080
Maintenance & Protection of Traffic	-0.007	-0.008	0.013	-0.048	0.018	0.039	-0.118	-0.124	-0.083	-0.084	0.030	0.110	-0.086
Temporary Access & Maintenance	1.000	0.008	0.008	-0.010	0.007	0.001	0.110	0.100	-0.027	0.017	-0.064	-0.065	0.004
SOE	0.008	1.000	-0.176	0.140	-0.006	-0.053	-0.079	-0.062	0.073	0.060	-0.085	-0.037	0.026
Dewatering	0.008	-0.176	1.000	0.008	0.010	0.085	-0.071	-0.048	0.098	-0.139	0.057	0.048	0.056
Crane Support	-0.010	0.140	0.008	1.000	0.015	-0.029	0.001	0.003	0.018	0.128	0.031	0.026	-0.087
Excavation	0.007	-0.006	0.010	0.015	1.000	0.009	-0.075	-0.108	-0.196	-0.047	-0.068	0.005	-0.080
Fills & Backfills	0.001	-0.053	0.085	-0.029	0.009	1.000	-0.068	-0.052	0.055	0.029	-0.022	0.087	0.014
Average Temperature (F)	0.110	-0.079	-0.071	0.001	-0.075	-0.068	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.100	-0.062	-0.048	0.003	-0.108	-0.052	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.027	0.073	0.098	0.018	-0.196	0.055	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.017	0.060	-0.139	0.128	-0.047	0.029	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.064	-0.085	0.057	0.031	-0.068	-0.022	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	-0.037	0.048	0.026	0.005	0.087	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	0.026	0.056	-0.087	-0.080	0.014	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.2.2.2 Excavation Correlation Matrix Based on Time

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic	Temporary Access & Maintenance
Office Supervision	1.000	0.484	0.129	0.671	0.437	0.569	0.570	0.197	0.008	-0.088	0.571	0.005
Field Supervision	0.484	1.000	0.023	0.343	0.170	0.343	0.294	0.279	-0.008	-0.059	0.320	0.002
Carpenter Foreman	0.129	0.023	1.000	-0.100	0.089	-0.292	0.410	-0.054	0.029	-0.098	-0.345	0.005
Master Mechanic & Maintenance Foreman	0.671	0.343	-0.100	1.000	0.514	0.868	0.584	0.091	-0.029	-0.062	0.845	0.015
Fuel, Oil, Grease for Equipment	0.437	0.170	0.089	0.514	1.000	0.452	0.454	0.407	-0.029	-0.041	0.427	-0.033
Labor Shop Steward	0.569	0.343	-0.292	0.868	0.452	1.000	0.504	0.047	-0.009	-0.012	0.942	0.008
Teamsters	0.570	0.294	0.410	0.584	0.454	0.504	1.000	0.002	0.023	-0.180	0.431	-0.048
Offsite Yard Crew	0.197	0.279	-0.054	0.091	0.407	0.047	0.002	1.000	-0.014	0.114	0.061	0.026
Survey Party	0.008	-0.008	0.029	-0.029	-0.029	-0.009	0.023	-0.014	1.000	-0.023	0.037	-0.008
Maintain Field Office	-0.088	-0.059	-0.098	-0.062	-0.041	-0.012	-0.180	0.114	-0.023	1.000	-0.020	-0.021
Maintenance & Protection of Traffic	0.571	0.320	-0.345	0.845	0.427	0.942	0.431	0.061	0.037	-0.020	1.000	-0.007
Temporary Access & Maintenance	0.005	0.002	0.005	0.015	-0.033	0.008	-0.048	0.026	-0.008	-0.021	-0.007	1.000
Dewatering	-0.002	0.005	-0.014	0.009	-0.012	0.000	-0.007	-0.172	0.007	-0.787	0.013	0.008
Concrete Support	0.064	0.015	0.090	-0.013	0.002	-0.026	0.046	0.087	-0.009	-0.076	-0.048	-0.010
Change Orders	0.533	0.312	-0.325	0.797	0.424	0.892	0.406	0.004	-0.006	-0.321	0.894	0.007
Average Temperature (F)	-0.189	-0.006	0.081	-0.097	-0.061	-0.040	0.013	-0.042	0.058	0.158	-0.118	0.110
Average Dewpoint (F)	-0.205	-0.020	0.076	-0.113	-0.068	-0.047	0.018	-0.047	0.088	0.121	-0.124	0.100
Average Humidity (%)	-0.136	-0.076	0.006	-0.128	-0.057	-0.065	0.031	-0.041	0.187	-0.140	-0.083	-0.027
Average Pressure (IN)	-0.095	-0.126	-0.083	-0.110	-0.064	-0.098	-0.035	0.219	0.012	0.076	-0.084	0.017
Average Wind Speed (MPH)	0.101	-0.049	0.051	-0.051	-0.015	-0.026	0.085	0.065	0.344	-0.103	0.030	-0.064
Maximum Gust Speed (MPH)	0.223	-0.068	-0.017	0.060	0.062	0.052	-0.007	0.036	0.104	-0.067	0.110	-0.065
Precipitation Sum (IN)	-0.049	-0.059	-0.013	-0.097	-0.022	-0.050	0.017	-0.021	0.074	-0.080	-0.086	0.004

Table C.2.3.1 Change Orders Correlation Matrix Based on Time

Activity	Dewatering	Concrete Support	Change Orders	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	-0.002	0.064	0.533	-0.189	-0.205	-0.136	-0.095	0.101	0.223	-0.049
Field Supervision	0.005	0.015	0.312	-0.006	-0.020	-0.076	-0.126	-0.049	-0.068	-0.059
Carpenter Foreman	-0.014	0.090	-0.325	0.081	0.076	0.006	-0.083	0.051	-0.017	-0.013
Master Mechanic & Maintenance Foreman	0.009	-0.013	0.797	-0.097	-0.113	-0.128	-0.110	-0.051	0.060	-0.097
Fuel, Oil, Grease for Equipment	-0.012	0.002	0.424	-0.061	-0.068	-0.057	-0.064	-0.015	0.062	-0.022
Labor Shop Steward	0.000	-0.026	0.892	-0.040	-0.047	-0.065	-0.098	-0.026	0.052	-0.050
Teamsters	-0.007	0.046	0.406	0.013	0.018	0.031	-0.035	0.085	-0.007	0.017
Offsite Yard Crew	-0.172	0.087	0.004	-0.042	-0.047	-0.041	0.219	0.065	0.036	-0.021
Survey Party	0.007	-0.009	-0.006	0.058	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	-0.787	-0.076	-0.321	0.158	0.121	-0.140	0.076	-0.103	-0.067	-0.080
Maintenance & Protection of Traffic	0.013	-0.048	0.894	-0.118	-0.124	-0.083	-0.084	0.030	0.110	-0.086
Temporary Access & Maintenance	0.008	-0.010	0.007	0.110	0.100	-0.027	0.017	-0.064	-0.065	0.004
Dewatering	1.000	0.008	0.389	-0.071	-0.048	0.098	-0.139	0.057	0.048	0.056
Concrete Support	0.008	1.000	-0.033	0.001	0.003	0.018	0.128	0.031	0.026	-0.087
Change Orders	0.389	-0.033	1.000	-0.137	-0.134	-0.038	-0.124	0.027	0.103	-0.016
Average Temperature (F)	-0.071	0.001	-0.137	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	-0.048	0.003	-0.134	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	0.098	0.018	-0.038	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	-0.139	0.128	-0.124	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	0.057	0.031	0.027	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	0.048	0.026	0.103	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.056	-0.087	-0.016	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.2.3.2 Change Orders Correlation Matrix Based on Time

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.484	0.129	0.671	0.437	0.569	0.570	0.197	0.008	-0.088	0.571
Field Supervision	0.484	1.000	0.023	0.343	0.170	0.343	0.294	0.279	-0.008	-0.059	0.320
Carpenter Foreman	0.129	0.023	1.000	-0.100	0.089	-0.292	0.410	-0.054	0.029	-0.098	-0.345
Master Mechanic & Maintenance Foreman	0.671	0.343	-0.100	1.000	0.514	0.868	0.584	0.091	-0.029	-0.062	0.845
Fuel, Oil, Grease for Equipment	0.437	0.170	0.089	0.514	1.000	0.452	0.454	0.407	-0.029	-0.041	0.427
Labor Shop Steward	0.569	0.343	-0.292	0.868	0.452	1.000	0.504	0.047	-0.009	-0.012	0.942
Teamsters	0.570	0.294	0.410	0.584	0.454	0.504	1.000	0.002	0.023	-0.180	0.431
Offsite Yard Crew	0.197	0.279	-0.054	0.091	0.407	0.047	0.002	1.000	-0.014	0.114	0.061
Survey Party	0.008	-0.008	0.029	-0.029	-0.029	-0.009	0.023	-0.014	1.000	-0.023	0.037
Maintain Field Office	-0.088	-0.059	-0.098	-0.062	-0.041	-0.012	-0.180	0.114	-0.023	1.000	-0.020
Maintenance & Protection of Traffic	0.571	0.320	-0.345	0.845	0.427	0.942	0.431	0.061	0.037	-0.020	1.000
Temporary Access & Maintenance	0.005	0.002	0.005	0.015	-0.033	0.008	-0.048	0.026	-0.008	-0.021	-0.007
Dewatering	-0.002	0.005	-0.014	0.009	-0.012	0.000	-0.007	-0.172	0.007	-0.787	0.013
Concrete Support	0.064	0.015	0.090	-0.013	0.002	-0.026	0.046	0.087	-0.009	-0.076	-0.048
Unit Price	0.145	0.459	-0.043	0.014	-0.027	0.070	-0.007	0.275	-0.017	0.064	0.024
Average Temperature (F)	-0.189	-0.006	0.081	-0.097	-0.061	-0.040	0.013	-0.042	0.058	0.158	-0.118
Average Dewpoint (F)	-0.205	-0.020	0.076	-0.113	-0.068	-0.047	0.018	-0.047	0.088	0.121	-0.124
Average Humidity (%)	-0.136	-0.076	0.006	-0.128	-0.057	-0.065	0.031	-0.041	0.187	-0.140	-0.083
Average Pressure (IN)	-0.095	-0.126	-0.083	-0.110	-0.064	-0.098	-0.035	0.219	0.012	0.076	-0.084
Average Wind Speed (MPH)	0.101	-0.049	0.051	-0.051	-0.015	-0.026	0.085	0.065	0.344	-0.103	0.030
Maximum Gust Speed (MPH)	0.223	-0.068	-0.017	0.060	0.062	0.052	-0.007	0.036	0.104	-0.067	0.110
Precipitation Sum (IN)	-0.049	-0.059	-0.013	-0.097	-0.022	-0.050	0.017	-0.021	0.074	-0.080	-0.086

Table C.2.4.1 Unit Prices Correlation Matrix Based on Time

Activity	Temporary Access & Maintenance	Dewatering	Concrete Support	Unit Price	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.005	-0.002	0.064	0.145	-0.189	-0.205	-0.136	-0.095	0.101	0.223	-0.049
Field Supervision	0.002	0.005	0.015	0.459	-0.006	-0.020	-0.076	-0.126	-0.049	-0.068	-0.059
Carpenter Foreman	0.005	-0.014	0.090	-0.043	0.081	0.076	0.006	-0.083	0.051	-0.017	-0.013
Master Mechanic & Maintenance Foreman	0.015	0.009	-0.013	0.014	-0.097	-0.113	-0.128	-0.110	-0.051	0.060	-0.097
Fuel, Oil, Grease for Equipment	-0.033	-0.012	0.002	-0.027	-0.061	-0.068	-0.057	-0.064	-0.015	0.062	-0.022
Labor Shop Steward	0.008	0.000	-0.026	0.070	-0.040	-0.047	-0.065	-0.098	-0.026	0.052	-0.050
Teamsters	-0.048	-0.007	0.046	-0.007	0.013	0.018	0.031	-0.035	0.085	-0.007	0.017
Offsite Yard Crew	0.026	-0.172	0.087	0.275	-0.042	-0.047	-0.041	0.219	0.065	0.036	-0.021
Survey Party	-0.008	0.007	-0.009	-0.017	0.058	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	-0.021	-0.787	-0.076	0.064	0.158	0.121	-0.140	0.076	-0.103	-0.067	-0.080
Maintenance & Protection of Traffic	-0.007	0.013	-0.048	0.024	-0.118	-0.124	-0.083	-0.084	0.030	0.110	-0.086
Temporary Access & Maintenance	1.000	0.008	-0.010	-0.018	0.110	0.100	-0.027	0.017	-0.064	-0.065	0.004
Dewatering	0.008	1.000	0.008	-0.101	-0.071	-0.048	0.098	-0.139	0.057	0.048	0.056
Concrete Support	-0.010	0.008	1.000	0.709	0.001	0.003	0.018	0.128	0.031	0.026	-0.087
Unit Price	-0.018	-0.101	0.709	1.000	-0.045	-0.039	0.016	0.109	0.060	-0.006	-0.076
Average Temperature (F)	0.110	-0.071	0.001	-0.045	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.100	-0.048	0.003	-0.039	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.027	0.098	0.018	0.016	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.017	-0.139	0.128	0.109	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.064	0.057	0.031	0.060	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	0.048	0.026	-0.006	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	0.056	-0.087	-0.076	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.2.4.2 Unit Prices Correlation Matrix Based on Time

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.484	0.129	0.671	0.437	0.569	0.570	0.197	0.008	-0.088	0.571
Field Supervision	0.484	1.000	0.023	0.343	0.170	0.343	0.294	0.279	-0.008	-0.059	0.320
Carpenter Foreman	0.129	0.023	1.000	-0.100	0.089	-0.292	0.410	-0.054	0.029	-0.098	-0.345
Master Mechanic & Maintenance Foreman	0.671	0.343	-0.100	1.000	0.514	0.868	0.584	0.091	-0.029	-0.062	0.845
Fuel, Oil, Grease for Equipment	0.437	0.170	0.089	0.514	1.000	0.452	0.454	0.407	-0.029	-0.041	0.427
Labor Shop Steward	0.569	0.343	-0.292	0.868	0.452	1.000	0.504	0.047	-0.009	-0.012	0.942
Teamsters	0.570	0.294	0.410	0.584	0.454	0.504	1.000	0.002	0.023	-0.180	0.431
Offsite Yard Crew	0.197	0.279	-0.054	0.091	0.407	0.047	0.002	1.000	-0.014	0.114	0.061
Survey Party	0.008	-0.008	0.029	-0.029	-0.029	-0.009	0.023	-0.014	1.000	-0.023	0.037
Maintain Field Office	-0.088	-0.059	-0.098	-0.062	-0.041	-0.012	-0.180	0.114	-0.023	1.000	-0.020
Maintenance & Protection of Traffic	0.571	0.320	-0.345	0.845	0.427	0.942	0.431	0.061	0.037	-0.020	1.000
Temporary Access & Maintenance	0.005	0.002	0.005	0.015	-0.033	0.008	-0.048	0.026	-0.008	-0.021	-0.007
Dewatering	-0.002	0.005	-0.014	0.009	-0.012	0.000	-0.007	-0.172	0.007	-0.787	0.013
Concrete Support	0.064	0.015	0.090	-0.013	0.002	-0.026	0.046	0.087	-0.009	-0.076	-0.048
Cut-Off, Haul & Dispose Piles	-0.114	-0.053	-0.097	-0.074	-0.093	-0.015	-0.180	0.006	-0.001	-0.018	0.004
Average Temperature (F)	-0.189	-0.006	0.081	-0.097	-0.061	-0.040	0.013	-0.042	0.058	0.158	-0.118
Average Dewpoint (F)	-0.205	-0.020	0.076	-0.113	-0.068	-0.047	0.018	-0.047	0.088	0.121	-0.124
Average Humidity (%)	-0.136	-0.076	0.006	-0.128	-0.057	-0.065	0.031	-0.041	0.187	-0.140	-0.083
Average Pressure (IN)	-0.095	-0.126	-0.083	-0.110	-0.064	-0.098	-0.035	0.219	0.012	0.076	-0.084
Average Wind Speed (MPH)	0.101	-0.049	0.051	-0.051	-0.015	-0.026	0.085	0.065	0.344	-0.103	0.030
Maximum Gust Speed (MPH)	0.223	-0.068	-0.017	0.060	0.062	0.052	-0.007	0.036	0.104	-0.067	0.110
Precipitation Sum (IN)	-0.049	-0.059	-0.013	-0.097	-0.022	-0.050	0.017	-0.021	0.074	-0.080	-0.086

Table C.2.5.1 Cut-Off, Haul & Dispose Piles Correlation Matrix Based on Time

Activity	Temporary Access & Maintenance	Dewatering	Concrete Support	Cut-Off, Haul & Dispose Piles	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.005	-0.002	0.064	-0.114	-0.189	-0.205	-0.136	-0.095	0.101	0.223	-0.049
Field Supervision	0.002	0.005	0.015	-0.053	-0.006	-0.020	-0.076	-0.126	-0.049	-0.068	-0.059
Carpenter Foreman	0.005	-0.014	0.090	-0.097	0.081	0.076	0.006	-0.083	0.051	-0.017	-0.013
Master Mechanic & Maintenance Foreman	0.015	0.009	-0.013	-0.074	-0.097	-0.113	-0.128	-0.110	-0.051	0.060	-0.097
Fuel, Oil, Grease for Equipment	-0.033	-0.012	0.002	-0.093	-0.061	-0.068	-0.057	-0.064	-0.015	0.062	-0.022
Labor Shop Steward	0.008	0.000	-0.026	-0.015	-0.040	-0.047	-0.065	-0.098	-0.026	0.052	-0.050
Teamsters	-0.048	-0.007	0.046	-0.180	0.013	0.018	0.031	-0.035	0.085	-0.007	0.017
Offsite Yard Crew	0.026	-0.172	0.087	0.006	-0.042	-0.047	-0.041	0.219	0.065	0.036	-0.021
Survey Party	-0.008	0.007	-0.009	-0.001	0.058	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	-0.021	-0.787	-0.076	-0.018	0.158	0.121	-0.140	0.076	-0.103	-0.067	-0.080
Maintenance & Protection of Traffic	-0.007	0.013	-0.048	0.004	-0.118	-0.124	-0.083	-0.084	0.030	0.110	-0.086
Temporary Access & Maintenance	1.000	0.008	-0.010	0.004	0.110	0.100	-0.027	0.017	-0.064	-0.065	0.004
Dewatering	0.008	1.000	0.008	-0.011	-0.071	-0.048	0.098	-0.139	0.057	0.048	0.056
Concrete Support	-0.010	0.008	1.000	-0.014	0.001	0.003	0.018	0.128	0.031	0.026	-0.087
Cut-Off, Haul & Dispose Piles	0.004	-0.011	-0.014	1.000	0.043	0.033	-0.047	-0.025	0.125	0.190	0.004
Average Temperature (F)	0.110	-0.071	0.001	0.043	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.100	-0.048	0.003	0.033	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.027	0.098	0.018	-0.047	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.017	-0.139	0.128	-0.025	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.064	0.057	0.031	0.125	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	0.048	0.026	0.190	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	0.056	-0.087	0.004	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.2.5.2 Cut-Off, Haul & Dispose Piles Correlation Matrix Based on Time

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.484	0.129	0.671	0.437	0.569	0.570	0.197	0.008	-0.088	0.571
Field Supervision	0.484	1.000	0.023	0.343	0.170	0.343	0.294	0.279	-0.008	-0.059	0.320
Carpenter Foreman	0.129	0.023	1.000	-0.100	0.089	-0.292	0.410	-0.054	0.029	-0.098	-0.345
Master Mechanic & Maintenance Foreman	0.671	0.343	-0.100	1.000	0.514	0.868	0.584	0.091	-0.029	-0.062	0.845
Fuel, Oil, Grease for Equipment	0.437	0.170	0.089	0.514	1.000	0.452	0.454	0.407	-0.029	-0.041	0.427
Labor Shop Steward	0.569	0.343	-0.292	0.868	0.452	1.000	0.504	0.047	-0.009	-0.012	0.942
Teamsters	0.570	0.294	0.410	0.584	0.454	0.504	1.000	0.002	0.023	-0.180	0.431
Offsite Yard Crew	0.197	0.279	-0.054	0.091	0.407	0.047	0.002	1.000	-0.014	0.114	0.061
Survey Party	0.008	-0.008	0.029	-0.029	-0.029	-0.009	0.023	-0.014	1.000	-0.023	0.037
Maintain Field Office	-0.088	-0.059	-0.098	-0.062	-0.041	-0.012	-0.180	0.114	-0.023	1.000	-0.020
Maintenance & Protection of Traffic	0.571	0.320	-0.345	0.845	0.427	0.942	0.431	0.061	0.037	-0.020	1.000
Temporary Access & Maintenance	0.005	0.002	0.005	0.015	-0.033	0.008	-0.048	0.026	-0.008	-0.021	-0.007
Dewatering	-0.002	0.005	-0.014	0.009	-0.012	0.000	-0.007	-0.172	0.007	-0.787	0.013
Concrete Support	0.064	0.015	0.090	-0.013	0.002	-0.026	0.046	0.087	-0.009	-0.076	-0.048
Concrete Demolition	-0.101	-0.525	-0.012	0.010	0.028	0.015	0.051	-0.148	0.006	-0.009	0.049
Average Temperature (F)	-0.189	-0.006	0.081	-0.097	-0.061	-0.040	0.013	-0.042	0.058	0.158	-0.118
Average Dewpoint (F)	-0.205	-0.020	0.076	-0.113	-0.068	-0.047	0.018	-0.047	0.088	0.121	-0.124
Average Humidity (%)	-0.136	-0.076	0.006	-0.128	-0.057	-0.065	0.031	-0.041	0.187	-0.140	-0.083
Average Pressure (IN)	-0.095	-0.126	-0.083	-0.110	-0.064	-0.098	-0.035	0.219	0.012	0.076	-0.084
Average Wind Speed (MPH)	0.101	-0.049	0.051	-0.051	-0.015	-0.026	0.085	0.065	0.344	-0.103	0.030
Maximum Gust Speed (MPH)	0.223	-0.068	-0.017	0.060	0.062	0.052	-0.007	0.036	0.104	-0.067	0.110
Precipitation Sum (IN)	-0.049	-0.059	-0.013	-0.097	-0.022	-0.050	0.017	-0.021	0.074	-0.080	-0.086

Table C.2.6.1 Concrete Demolition Correlation Matrix Based on Time

Activity	Temporary Access & Maintenance	Dewatering	Crane Support	Concrete Demolition	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.005	-0.002	0.064	-0.101	-0.189	-0.205	-0.136	-0.095	0.101	0.223	-0.049
Field Supervision	0.002	0.005	0.015	-0.525	-0.006	-0.020	-0.076	-0.126	-0.049	-0.068	-0.059
Carpenter Foreman	0.005	-0.014	0.090	-0.012	0.081	0.076	0.006	-0.083	0.051	-0.017	-0.013
Master Mechanic & Maintenance Foreman	0.015	0.009	-0.013	0.010	-0.097	-0.113	-0.128	-0.110	-0.051	0.060	-0.097
Fuel, Oil, Grease for Equipment	-0.033	-0.012	0.002	0.028	-0.061	-0.068	-0.057	-0.064	-0.015	0.062	-0.022
Labor Shop Steward	0.008	0.000	-0.026	0.015	-0.040	-0.047	-0.065	-0.098	-0.026	0.052	-0.050
Teamsters	-0.048	-0.007	0.046	0.051	0.013	0.018	0.031	-0.035	0.085	-0.007	0.017
Offsite Yard Crew	0.026	-0.172	0.087	-0.148	-0.042	-0.047	-0.041	0.219	0.065	0.036	-0.021
Survey Party	-0.008	0.007	-0.009	0.006	0.058	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	-0.021	-0.787	-0.076	-0.009	0.158	0.121	-0.140	0.076	-0.103	-0.067	-0.080
Maintenance & Protection of Traffic	-0.007	0.013	-0.048	0.049	-0.118	-0.124	-0.083	-0.084	0.030	0.110	-0.086
Temporary Access & Maintenance	1.000	0.008	-0.010	0.006	0.110	0.100	-0.027	0.017	-0.064	-0.065	0.004
Dewatering	0.008	1.000	0.008	-0.001	-0.071	-0.048	0.098	-0.139	0.057	0.048	0.056
Concrete Support	-0.010	0.008	1.000	0.009	0.001	0.003	0.018	0.128	0.031	0.026	-0.087
Concrete Demolition	0.006	-0.001	0.009	1.000	-0.006	-0.012	-0.028	0.106	0.089	0.046	0.077
Average Temperature (F)	0.110	-0.071	0.001	-0.006	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.100	-0.048	0.003	-0.012	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.027	0.098	0.018	-0.028	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.017	-0.139	0.128	0.106	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.064	0.057	0.031	0.089	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	0.048	0.026	0.046	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	0.056	-0.087	0.077	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.2.6.2 Concrete Demolition Correlation Matrix Based on Time

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.484	0.129	0.671	0.437	0.569	0.570	0.197	0.008	-0.088	0.571
Field Supervision	0.484	1.000	0.023	0.343	0.170	0.343	0.294	0.279	-0.008	-0.059	0.320
Carpenter Foreman	0.129	0.023	1.000	-0.100	0.089	-0.292	0.410	-0.054	0.029	-0.098	-0.345
Master Mechanic & Maintenance Foreman	0.671	0.343	-0.100	1.000	0.514	0.868	0.584	0.091	-0.029	-0.062	0.845
Fuel, Oil, Grease for Equipment	0.437	0.170	0.089	0.514	1.000	0.452	0.454	0.407	-0.029	-0.041	0.427
Labor Shop Steward	0.569	0.343	-0.292	0.868	0.452	1.000	0.504	0.047	-0.009	-0.012	0.942
Teamsters	0.570	0.294	0.410	0.584	0.454	0.504	1.000	0.002	0.023	-0.180	0.431
Offsite Yard Crew	0.197	0.279	-0.054	0.091	0.407	0.047	0.002	1.000	-0.014	0.114	0.061
Survey Party	0.008	-0.008	0.029	-0.029	-0.029	-0.009	0.023	-0.014	1.000	-0.023	0.037
Maintain Field Office	-0.088	-0.059	-0.098	-0.062	-0.041	-0.012	-0.180	0.114	-0.023	1.000	-0.020
Maintenance & Protection of Traffic	0.571	0.320	-0.345	0.845	0.427	0.942	0.431	0.061	0.037	-0.020	1.000
Temporary Access & Maintenance	0.005	0.002	0.005	0.015	-0.033	0.008	-0.048	0.026	-0.008	-0.021	-0.007
Dewatering	-0.002	0.005	-0.014	0.009	-0.012	0.000	-0.007	-0.172	0.007	-0.787	0.013
Crane Support	0.064	0.015	0.090	-0.013	0.002	-0.026	0.046	0.087	-0.009	-0.076	-0.048
F+I Structural Steel	0.025	0.026	0.003	-0.014	-0.072	0.041	-0.005	0.042	0.016	-0.005	0.027
F+I Miscellaneous Metal	0.087	0.014	0.288	-0.039	0.155	-0.002	0.127	0.314	-0.010	0.546	-0.031
Average Temperature (F)	-0.189	-0.006	0.081	-0.097	-0.061	-0.040	0.013	-0.042	0.058	0.158	-0.118
Average Dewpoint (F)	-0.205	-0.020	0.076	-0.113	-0.068	-0.047	0.018	-0.047	0.088	0.121	-0.124
Average Humidity (%)	-0.136	-0.076	0.006	-0.128	-0.057	-0.065	0.031	-0.041	0.187	-0.140	-0.083
Average Pressure (IN)	-0.095	-0.126	-0.083	-0.110	-0.064	-0.098	-0.035	0.219	0.012	0.076	-0.084
Average Wind Speed (MPH)	0.101	-0.049	0.051	-0.051	-0.015	-0.026	0.085	0.065	0.344	-0.103	0.030
Maximum Gust Speed (MPH)	0.223	-0.068	-0.017	0.060	0.062	0.052	-0.007	0.036	0.104	-0.067	0.110
Precipitation Sum (IN)	-0.049	-0.059	-0.013	-0.097	-0.022	-0.050	0.017	-0.021	0.074	-0.080	-0.086

Table C.2.7.1 Metal Correlation Matrix Based on Time

Activity	Temporary Access & Maintenance	Dewatering	Crane Support	F&I Structural Steel	F&I Miscellaneous Metal	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.005	-0.002	0.064	0.025	0.087	-0.189	-0.205	-0.136	-0.095	0.101	0.223	-0.049
Field Supervision	0.002	0.005	0.015	0.026	0.014	-0.006	-0.020	-0.076	-0.126	-0.049	-0.068	-0.059
Carpenter Foreman	0.005	-0.014	0.090	0.003	0.288	0.081	0.076	0.006	-0.083	0.051	-0.017	-0.013
Master Mechanic & Maintenance Foreman	0.015	0.009	-0.013	-0.014	-0.039	-0.097	-0.113	-0.128	-0.110	-0.051	0.060	-0.097
Fuel, Oil, Grease for Equipment	-0.033	-0.012	0.002	-0.072	0.155	-0.061	-0.068	-0.057	-0.064	-0.015	0.062	-0.022
Labor Shop Steward	0.008	0.000	-0.026	0.041	-0.002	-0.040	-0.047	-0.065	-0.098	-0.026	0.052	-0.050
Teamsters	-0.048	-0.007	0.046	-0.005	0.127	0.013	0.018	0.031	-0.035	0.085	-0.007	0.017
Offsite Yard Crew	0.026	-0.172	0.087	0.042	0.314	-0.042	-0.047	-0.041	0.219	0.065	0.036	-0.021
Survey Party	-0.008	0.007	-0.009	0.016	-0.010	0.058	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	-0.021	-0.787	-0.076	-0.005	0.546	0.158	0.121	-0.140	0.076	-0.103	-0.067	-0.080
Maintenance & Protection of Traffic	-0.007	0.013	-0.048	0.027	-0.031	-0.118	-0.124	-0.083	-0.084	0.030	0.110	-0.086
Temporary Access & Maintenance	1.000	0.008	-0.010	0.013	-0.019	0.110	0.100	-0.027	0.017	-0.064	-0.065	0.004
Dewatering	0.008	1.000	0.008	-0.018	-0.702	-0.071	-0.048	0.098	-0.139	0.057	0.048	0.056
Crane Support	-0.010	0.008	1.000	0.086	-0.118	0.001	0.003	0.018	0.128	0.031	0.026	-0.087
F+I Structural Steel	0.013	-0.018	0.086	1.000	-0.034	0.018	0.009	-0.037	-0.082	0.196	0.064	0.057
F+I Miscellaneous Metal	-0.019	-0.702	-0.118	-0.034	1.000	0.098	0.086	-0.035	0.152	-0.038	-0.010	0.005
Average Temperature (F)	0.110	-0.071	0.001	0.018	0.098	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.100	-0.048	0.003	0.009	0.086	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.027	0.098	0.018	-0.037	-0.035	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.017	-0.139	0.128	-0.082	0.152	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.064	0.057	0.031	0.196	-0.038	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	0.048	0.026	0.064	-0.010	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	0.056	-0.087	0.057	0.005	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.2.7.2 Metal Correlation Matrix Based on Time

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.484	0.129	0.671	0.437	0.569	0.570	0.197	0.008	-0.088	0.571
Field Supervision	0.484	1.000	0.023	0.343	0.170	0.343	0.294	0.279	-0.008	-0.059	0.320
Carpenter Foreman	0.129	0.023	1.000	-0.100	0.089	-0.292	0.410	-0.054	0.029	-0.098	-0.345
Master Mechanic & Maintenance Foreman	0.671	0.343	-0.100	1.000	0.514	0.868	0.584	0.091	-0.029	-0.062	0.845
Fuel, Oil, Grease for Equipment	0.437	0.170	0.089	0.514	1.000	0.452	0.454	0.407	-0.029	-0.041	0.427
Labor Shop Steward	0.569	0.343	-0.292	0.868	0.452	1.000	0.504	0.047	-0.009	-0.012	0.942
Teamsters	0.570	0.294	0.410	0.584	0.454	0.504	1.000	0.002	0.023	-0.180	0.431
Offsite Yard Crew	0.197	0.279	-0.054	0.091	0.407	0.047	0.002	1.000	-0.014	0.114	0.061
Survey Party	0.008	-0.008	0.029	-0.029	-0.029	-0.009	0.023	-0.014	1.000	-0.023	0.037
Maintain Field Office	-0.088	-0.059	-0.098	-0.062	-0.041	-0.012	-0.180	0.114	-0.023	1.000	-0.020
Maintenance & Protection of Traffic	0.571	0.320	-0.345	0.845	0.427	0.942	0.431	0.061	0.037	-0.020	1.000
Temporary Access & Maintenance	0.005	0.002	0.005	0.015	-0.033	0.008	-0.048	0.026	-0.008	-0.021	-0.007
Dewatering	-0.002	0.005	-0.014	0.009	-0.012	0.000	-0.007	-0.172	0.007	-0.787	0.013
Crane Support	0.064	0.015	0.090	-0.013	0.002	-0.026	0.046	0.087	-0.009	-0.076	-0.048
Furnish & Install Pipes & Fittings	-0.012	0.005	0.035	0.030	-0.001	0.006	0.016	-0.162	0.009	-0.318	0.014
Mechanical	0.064	0.033	-0.099	0.117	-0.020	0.101	0.053	-0.143	0.002	-0.743	0.124
Average Temperature (F)	-0.189	-0.006	0.081	-0.097	-0.061	-0.040	0.013	-0.042	0.058	0.158	-0.118
Average Dewpoint (F)	-0.205	-0.020	0.076	-0.113	-0.068	-0.047	0.018	-0.047	0.088	0.121	-0.124
Average Humidity (%)	-0.136	-0.076	0.006	-0.128	-0.057	-0.065	0.031	-0.041	0.187	-0.140	-0.083
Average Pressure (IN)	-0.095	-0.126	-0.083	-0.110	-0.064	-0.098	-0.035	0.219	0.012	0.076	-0.084
Average Wind Speed (MPH)	0.101	-0.049	0.051	-0.051	-0.015	-0.026	0.085	0.065	0.344	-0.103	0.030
Maximum Gust Speed (MPH)	0.223	-0.068	-0.017	0.060	0.062	0.052	-0.007	0.036	0.104	-0.067	0.110
Precipitation Sum (IN)	-0.049	-0.059	-0.013	-0.097	-0.022	-0.050	0.017	-0.021	0.074	-0.080	-0.086

Table C.2.8.1 Mechanical Correlation Matrix Based on Time

Activity	Temporary Access & Maintenance	Dewatering	Crane Support	Pipes & Fittings	Mechanical	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.005	-0.002	0.064	-0.012	0.064	-0.189	-0.205	-0.136	-0.095	0.101	0.223	-0.049
Field Supervision	0.002	0.005	0.015	0.005	0.033	-0.006	-0.020	-0.076	-0.126	-0.049	-0.068	-0.059
Carpenter Foreman	0.005	-0.014	0.090	0.035	-0.099	0.081	0.076	0.006	-0.083	0.051	-0.017	-0.013
Master Mechanic & Maintenance Foreman	0.015	0.009	-0.013	0.030	0.117	-0.097	-0.113	-0.128	-0.110	-0.051	0.060	-0.097
Fuel, Oil, Grease for Equipment	-0.033	-0.012	0.002	-0.001	-0.020	-0.061	-0.068	-0.057	-0.064	-0.015	0.062	-0.022
Labor Shop Steward	0.008	0.000	-0.026	0.006	0.101	-0.040	-0.047	-0.065	-0.098	-0.026	0.052	-0.050
Teamsters	-0.048	-0.007	0.046	0.016	0.053	0.013	0.018	0.031	-0.035	0.085	-0.007	0.017
Offsite Yard Crew	0.026	-0.172	0.087	-0.162	-0.143	-0.042	-0.047	-0.041	0.219	0.065	0.036	-0.021
Survey Party	-0.008	0.007	-0.009	0.009	0.002	0.058	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	-0.021	-0.787	-0.076	-0.318	-0.743	0.158	0.121	-0.140	0.076	-0.103	-0.067	-0.080
Maintenance & Protection of Traffic	-0.007	0.013	-0.048	0.014	0.124	-0.118	-0.124	-0.083	-0.084	0.030	0.110	-0.086
Temporary Access & Maintenance	1.000	0.008	-0.010	0.007	0.005	0.110	0.100	-0.027	0.017	-0.064	-0.065	0.004
Dewatering	0.008	1.000	0.008	0.392	0.956	-0.071	-0.048	0.098	-0.139	0.057	0.048	0.056
Crane Support	-0.010	0.008	1.000	-0.740	-0.007	0.001	0.003	0.018	0.128	0.031	0.026	-0.087
Furnish & Install Pipes & Fittings	0.007	0.392	-0.740	1.000	0.376	0.030	0.032	0.013	-0.114	0.002	-0.016	0.062
Mechanical	0.005	0.956	-0.007	0.376	1.000	-0.136	-0.113	0.068	-0.115	0.062	0.052	0.041
Average Temperature (F)	0.110	-0.071	0.001	0.030	-0.136	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.100	-0.048	0.003	0.032	-0.113	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.027	0.098	0.018	0.013	0.068	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.017	-0.139	0.128	-0.114	-0.115	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.064	0.057	0.031	0.002	0.062	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	0.048	0.026	-0.016	0.052	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	0.056	-0.087	0.062	0.041	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.2.8.2 Mechanical Correlation Matrix Based on Time

Activity	Office Supervision	Field Supervision	Carpenter Foreman	Master Mechanic & Maintenance Foreman	Fuel, Oil, Grease for Equipment	Labor Shop Steward	Teamsters	Offsite Yard Crew	Survey Party	Maintain Field Office	Maintenance & Protection of Traffic
Office Supervision	1.000	0.484	0.129	0.671	0.437	0.569	0.570	0.197	0.008	-0.088	0.571
Field Supervision	0.484	1.000	0.023	0.343	0.170	0.343	0.294	0.279	-0.008	-0.059	0.320
Carpenter Foreman	0.129	0.023	1.000	-0.100	0.089	-0.292	0.410	-0.054	0.029	-0.098	-0.345
Master Mechanic & Maintenance Foreman	0.671	0.343	-0.100	1.000	0.514	0.868	0.584	0.091	-0.029	-0.062	0.845
Fuel, Oil, Grease for Equipment	0.437	0.170	0.089	0.514	1.000	0.452	0.454	0.407	-0.029	-0.041	0.427
Labor Shop Steward	0.569	0.343	-0.292	0.868	0.452	1.000	0.504	0.047	-0.009	-0.012	0.942
Teamsters	0.570	0.294	0.410	0.584	0.454	0.504	1.000	0.002	0.023	-0.180	0.431
Offsite Yard Crew	0.197	0.279	-0.054	0.091	0.407	0.047	0.002	1.000	-0.014	0.114	0.061
Survey Party	0.008	-0.008	0.029	-0.029	-0.029	-0.009	0.023	-0.014	1.000	-0.023	0.037
Maintain Field Office	-0.088	-0.059	-0.098	-0.062	-0.041	-0.012	-0.180	0.114	-0.023	1.000	-0.020
Maintenance & Protection of Traffic	0.571	0.320	-0.345	0.845	0.427	0.942	0.431	0.061	0.037	-0.020	1.000
Temporary Access & Maintenance	0.005	0.002	0.005	0.015	-0.033	0.008	-0.048	0.026	-0.008	-0.021	-0.007
Dewatering	-0.002	0.005	-0.014	0.009	-0.012	0.000	-0.007	-0.172	0.007	-0.787	0.013
Crane Support	0.064	0.015	0.090	-0.013	0.002	-0.026	0.046	0.087	-0.009	-0.076	-0.048
Thermal & Moist Protection	-0.030	-0.050	-0.006	-0.061	-0.104	0.033	-0.001	-0.041	-0.021	-0.056	-0.040
Doors & Windows	-0.121	-0.033	-0.287	-0.037	-0.030	-0.051	-0.249	-0.084	-0.009	-0.233	0.000
Average Temperature (F)	-0.189	-0.006	0.081	-0.097	-0.061	-0.040	0.013	-0.042	0.058	0.158	-0.118
Average Dewpoint (F)	-0.205	-0.020	0.076	-0.113	-0.068	-0.047	0.018	-0.047	0.088	0.121	-0.124
Average Humidity (%)	-0.136	-0.076	0.006	-0.128	-0.057	-0.065	0.031	-0.041	0.187	-0.140	-0.083
Average Pressure (IN)	-0.095	-0.126	-0.083	-0.110	-0.064	-0.098	-0.035	0.219	0.012	0.076	-0.084
Average Wind Speed (MPH)	0.101	-0.049	0.051	-0.051	-0.015	-0.026	0.085	0.065	0.344	-0.103	0.030
Maximum Gust Speed (MPH)	0.223	-0.068	-0.017	0.060	0.062	0.052	-0.007	0.036	0.104	-0.067	0.110
Precipitation Sum (IN)	-0.049	-0.059	-0.013	-0.097	-0.022	-0.050	0.017	-0.021	0.074	-0.080	-0.086

Table C.2.9.1 Architectural Correlation Matrix Based on Time

Activity	Temporary Access & Maintenance	Dewatering	Crane Support	Thermal & Moist Protection	Doors & Windows	Average Temperature (F)	Average Dewpoint (F)	Average Humidity (%)	Average Pressure (IN)	Average Wind Speed (MPH)	Maximum Gust Speed (MPH)	Precipitation Sum (IN)
Office Supervision	0.005	-0.002	0.064	-0.030	-0.121	-0.189	-0.205	-0.136	-0.095	0.101	0.223	-0.049
Field Supervision	0.002	0.005	0.015	-0.050	-0.033	-0.006	-0.020	-0.076	-0.126	-0.049	-0.068	-0.059
Carpenter Foreman	0.005	-0.014	0.090	-0.006	-0.287	0.081	0.076	0.006	-0.083	0.051	-0.017	-0.013
Master Mechanic & Maintenance Foreman	0.015	0.009	-0.013	-0.061	-0.037	-0.097	-0.113	-0.128	-0.110	-0.051	0.060	-0.097
Fuel, Oil, Grease for Equipment	-0.033	-0.012	0.002	-0.104	-0.030	-0.061	-0.068	-0.057	-0.064	-0.015	0.062	-0.022
Labor Shop Steward	0.008	0.000	-0.026	0.033	-0.051	-0.040	-0.047	-0.065	-0.098	-0.026	0.052	-0.050
Teamsters	-0.048	-0.007	0.046	-0.001	-0.249	0.013	0.018	0.031	-0.035	0.085	-0.007	0.017
Offsite Yard Crew	0.026	-0.172	0.087	-0.041	-0.084	-0.042	-0.047	-0.041	0.219	0.065	0.036	-0.021
Survey Party	-0.008	0.007	-0.009	-0.021	-0.009	0.058	0.088	0.187	0.012	0.344	0.104	0.074
Maintain Field Office	-0.021	-0.787	-0.076	-0.056	-0.233	0.158	0.121	-0.140	0.076	-0.103	-0.067	-0.080
Maintenance & Protection of Traffic	-0.007	0.013	-0.048	-0.040	0.000	-0.118	-0.124	-0.083	-0.084	0.030	0.110	-0.086
Temporary Access & Maintenance	1.000	0.008	-0.010	-0.030	0.009	0.110	0.100	-0.027	0.017	-0.064	-0.065	0.004
Dewatering	0.008	1.000	0.008	0.111	0.401	-0.071	-0.048	0.098	-0.139	0.057	0.048	0.056
Crane Support	-0.010	0.008	1.000	-0.009	-0.008	0.001	0.003	0.018	0.128	0.031	0.026	-0.087
Thermal & Moist Protection	-0.030	0.111	-0.009	1.000	-0.409	-0.092	-0.082	0.029	0.182	0.159	-0.065	-0.008
Doors & Windows	0.009	0.401	-0.008	-0.409	1.000	-0.033	-0.028	0.027	-0.100	-0.177	-0.094	0.088
Average Temperature (F)	0.110	-0.071	0.001	-0.092	-0.033	1.000	0.982	0.214	-0.201	-0.243	-0.139	-0.038
Average Dewpoint (F)	0.100	-0.048	0.003	-0.082	-0.028	0.982	1.000	0.395	-0.209	-0.197	-0.161	0.030
Average Humidity (%)	-0.027	0.098	0.018	0.029	0.027	0.214	0.395	1.000	-0.108	0.190	-0.137	0.366
Average Pressure (IN)	0.017	-0.139	0.128	0.182	-0.100	-0.201	-0.209	-0.108	1.000	-0.016	-0.055	-0.255
Average Wind Speed (MPH)	-0.064	0.057	0.031	0.159	-0.177	-0.243	-0.197	0.190	-0.016	1.000	0.498	0.283
Maximum Gust Speed (MPH)	-0.065	0.048	0.026	-0.065	-0.094	-0.139	-0.161	-0.137	-0.055	0.498	1.000	0.081
Precipitation Sum (IN)	0.004	0.056	-0.087	-0.008	0.088	-0.038	0.030	0.366	-0.255	0.283	0.081	1.000

Table C.2.9.2 Architectural Correlation Matrix Based on Time

D.1 Properties of Continuous Probability Distributions:

D.1.1 $\text{RISKBetaGeneral}(\alpha_1, \alpha_2, \text{min}, \text{max})$

D.1.2 $\text{RISKExpon}(\beta)$

D.1.3 $\text{RISKExtValue}(a, b)$

D.1.4 $\text{RiskInvGauss}(\mu, \lambda)$

D.1.5 $\text{RiskLogisitic}(\alpha, \beta)$

D.1.6 $\text{RISKLogLogistic}(\gamma, \beta, \alpha)$

D.1.7 $\text{RISKNormal}(\mu, \sigma)$

D.1.8 $\text{RISKPearson5}(\alpha, \beta)$

D.1.9 $\text{RISKTriang}(\text{min}, \text{m. likely}, \text{max}))$

D.2 Continuous Probability Distribution Graphs Based on Cost for:

D.2.1 Furnish Formwork, Rebar and Concrete

D.2.2 Install Formwork

D.2.3 Install Rebar

D.2.4 Pour Concrete

D.2.5 Finish Concrete

D.2.6 Furnish & Install Grout

D.1.7 Excavation

D.2.8 Place Fills

D.2.9 Change Orders

D.2.10 Unit Prices

D.2.11 Cut-Off, Haul & Dispose Piles

D.2.12 Concrete Demolition

D.2.13 Furnish & Install Structural Steel

D.2.14 Furnish & Install Miscellaneous Metals

D.2.15 Mechanical

D.2.16 Furnish & Install Pipes & Fittings

D.2.17 Furnish & Install Thermal and Moist Protection

D.2.18 Furnish & Install Doors and Windows

D.3 Continuous Probability Distribution Graphs Based on Time for:

D.3.1 Furnish Formwork, Rebar and Concrete

D.3.2 Install Formwork

D.3.3 Install Rebar

D.3.4 Pour Concrete

D.3.5 Finish Concrete

D.3.6 Furnish & Install Grout

D.3.7 Excavation

D.3.8 Place Fills

D.3.9 Change Orders

D.3.10 Unit Prices

D.3.11 Cut-Off, Haul & Dispose Piles

D.3.12 Concrete Demolition

D.3.13 Furnish & Install Structural Steel

D.3.14 Furnish & Install Miscellaneous Metals

D.3.15 Mechanical

D.3.16 Furnish & Install Pipes & Fittings

D.3.17 Furnish & Install Thermal and Moist Protection

D.3.18 Furnish & Install Doors and Windows

D.4 Fitted Distribution Run Results Based on Cost:

D.4.1 1 and 2

D.4.2 3 and 4

D.4.3 5 and 6

D.4.4 7

D.5 Fitted Distribution Run Results Based on Time:

D.5.1 1 and 2

D.5.2 3 and 4

D.5.3 5 and 6

D.5.4 7

Appendix D.1.1 RISKBetaGeneral($\alpha_1, \alpha_2, \min, \max$)

Parameters:

α_1	continuous shape parameter	$\alpha_1 > 0$
α_2	continuous shape parameter	$\alpha_2 > 0$
$\min$	continuous boundary parameter	$\min < \max$
$\max$	continuous boundary parameter	

Domain: $\min \leq x \leq \max$ continuous

Density Function:
$$f(x) = \frac{(x - \min)^{\alpha_1 - 1} (\max - x)^{\alpha_2 - 1}}{B(\alpha_1, \alpha_2)(\max - \min)^{\alpha_1 + \alpha_2 - 1}}$$

Cumulative Distribution Function:
$$F(x) = \frac{B_z(\alpha_1, \alpha_2)}{B(\alpha_1, \alpha_2)} \equiv I_z(\alpha_1, \alpha_2) \text{ with } z \equiv \frac{x - \min}{\max - \min}$$

where B is the Beta Function and B_z is the Incomplete Beta Function.

Mean:
$$\min + \frac{\alpha_1}{\alpha_1 + \alpha_2} (\max - \min)$$

Variance:
$$\frac{\alpha_1 \alpha_2}{(\alpha_1 + \alpha_2)^2 (\alpha_1 + \alpha_2 + 1)} (\max - \min)^2$$

Skewness:
$$2 \frac{\alpha_2 - \alpha_1}{\alpha_1 + \alpha_2 + 2} \sqrt{\frac{\alpha_1 + \alpha_2 + 1}{\alpha_1 \alpha_2}}$$

Kurtosis:
$$3 \frac{(\alpha_1 + \alpha_2 + 1)(2(\alpha_1 + \alpha_2)^2 + \alpha_1 \alpha_2 (\alpha_1 + \alpha_2 - 6))}{\alpha_1 \alpha_2 (\alpha_1 + \alpha_2 + 2)(\alpha_1 + \alpha_2 + 3)}$$

Mode:

$$\min + \frac{\alpha_1 - 1}{\alpha_1 + \alpha_2 - 2} (\max - \min) \quad \alpha_1 > 1, \alpha_2 > 1$$

Min $\alpha_1 < 1, \alpha_2 \geq 1$ or $\alpha_1 = 1, \alpha_2 > 1$

Max $\alpha_1 \geq 1, \alpha_2 < 1$ or $\alpha_1 > 1, \alpha_2 = 1$

Appendix D.1.2 RISKExpon(β)

Parameters: β continuous scale parameter $\beta > 0$

Domain: $0 \leq x < +\infty$ continuous

Density Function: $f(x) = \frac{e^{-x/\beta}}{\beta}$

Cumulative Distribution Function: $F(x) = 1 - e^{-x/\beta}$

Mean: β

Variance: β^2

Skewness: 2

Kurtosis: 9

Mode: 0

Appendix D.1.3 RISKEstValue(a, b)

Parameters: a Continuous location parameter
 b Continuous Scale Parameter $b > 0$

Domain: $-\infty \leq x \leq +\infty$ continuous

Density Function: $f(x) = \frac{1}{b} \left(\frac{1}{e^{z + \exp(-z)}} \right)$

Cumulative Distribution Function: $F(x) = \frac{1}{e^{\exp(-z)}}$ where $z \equiv \frac{(x-a)}{b}$

Mean: $a - b\Gamma'(1) \approx a + 0.577b$ where $\Gamma'(x)$ is the derivative of the Gamma Function.

Variance: $\frac{\pi^2 b^2}{6}$

Skewness: 1.139547

Kurtosis: 5.4

Mode: a

Appendix D.1.4 RiskInvGauss(μ, λ)

Parameters: μ continuous parameter $\mu > 0$
 λ continuous parameter $\lambda > 0$

Domain: $x > 0$ continuous

Density Functions: $f(x) = \sqrt{\frac{\lambda}{2\pi x^3}} e^{-\left[\frac{\lambda(x-\mu^2)}{2\mu^2 x}\right]}$

Cumulative Distribution Function: $F(x) = \Phi\left[\sqrt{\frac{\lambda}{x}}\left(\frac{x}{\mu} - 1\right)\right] + e^{2\lambda/\mu} \Phi\left[-\sqrt{\frac{\lambda}{x}}\left(\frac{x}{\mu} + 1\right)\right]$

where Φ is the Error Function.

Mean: μ

Variance: $\frac{\mu^3}{\lambda}$

Skewness: $\sqrt[3]{\frac{\mu}{\lambda}}$

Kurtosis: $3 + 15\frac{\mu}{\lambda}$

Mode: $\mu\left[\left(1 + \frac{9\mu^2}{4\lambda^2}\right) - \frac{3\mu}{2\lambda}\right]$

Appendix D.1.5 RiskLogistic(α, β)

Parameters: α continuous location parameter
 β continuous scale parameter $\beta > 0$

Domain: $-\infty \leq x \leq +\infty$ continuous

Density Functions: $f(x) = \frac{\text{sech}^2\left(\frac{1}{2}\left(\frac{x-\alpha}{\beta}\right)\right)}{4\beta}$

Cumulative Distribution Function: $F(x) = \frac{1 + \tanh\left(\frac{1}{2}\left(\frac{x-\alpha}{\beta}\right)\right)}{2}$ where “sech” is the Hyperbolic Secant Function and “tanh” is the Hyperbolic Tangent Function.

Mean: α

Variance: $\frac{\pi^2 \beta^2}{3}$

Skewness: 0

Kurtosis: 4.2

Mode: α

Appendix D.1.6 RISKLogLogistic(γ, β, α)

Parameters:

γ	continuous location parameter	
α	continuous scale parameter	$\alpha > 0$
β	continuous shape parameter	$\beta > 0$

Definitions: $\theta \equiv \frac{\pi}{\alpha}$

Domain: $\gamma \leq x \leq +\infty$ continuous

Density Function: $f(x) = \frac{\alpha t^{\alpha-1}}{\beta(1+t^\alpha)^2}$

Cumulative Distribution Function: $F(x) = \frac{1}{1+\left(\frac{1}{t}\right)^\alpha}$ with $t \equiv \frac{x-\gamma}{\beta}$

Mean: $\beta\theta \csc(\theta) + \gamma$ for $\alpha > 1$

Variance: $\beta^2\theta[2 \csc(2\theta) - \theta \csc^2(\theta)]$ for $\alpha > 2$

Skewness: $\frac{3 \csc(3\theta) - 6\theta \csc(2\theta) \csc(\theta) + 2\theta^2 \csc^3(\theta)}{\sqrt{\theta}[2 \csc(2\theta) - \theta \csc^2(\theta)]^{3/2}}$

Mode:

$\gamma + \beta \left[\frac{\alpha-1}{\alpha+1} \right]^{\frac{1}{\alpha}}$	for $\alpha > 1$
0	for $\alpha \leq 1$

Appendix D.1.7 RISKNormal(μ, σ)

Parameters: μ continuous location parameter
 σ continuous scale parameter $\sigma > 0$

Domain: $-\infty \leq x \leq +\infty$ continuous

Density Function: $f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$

Cumulative Distribution Function: $F(x) = \Phi\left(\frac{x-\mu}{\sigma}\right)$ where Φ is the Error Function.

Mean: μ

Variance: σ^2

Skewness: 0

Kurtosis: 3

Mode: μ

Appendix D.1.8 RISKPearson5(α, β)

Parameters: α continuous shape parameter $\alpha > 0$
 β continuous scale parameter $\beta > 0$

Domain: $0 \leq x \leq +\infty$ continuous

Density Function: $f(x) = \frac{1}{\beta \Gamma(\alpha)} \frac{e^{-\beta/x}}{(x/\beta)^{\alpha+1}}$

Cumulative Distribution Function: $F(x)$ has no closed form.

Mean: $\frac{\beta}{\alpha-1}$ for $\alpha > 1$

Variance: $\frac{\beta^2}{(\alpha-1)^2(\alpha-2)}$ for $\alpha > 2$

Skewness: $\frac{4\sqrt{\alpha-2}}{\alpha-3}$ for $\alpha > 3$

Kurtosis: $\frac{3(\alpha+5)(\alpha-2)}{(\alpha-3)(\alpha-4)}$ for $\alpha > 4$

Mode: $\frac{\beta}{\alpha+1}$

Appendix D.1.9 RISKTriang(min, m. likely, max))

Parameters:

min	continuous boundary parameter	$\min < \max$
m. likely	continuous mode parameter	$\min \leq \text{m.likely} \leq \max$
max	continuous boundary parameter	

Domain: $\min \leq x \leq \max$ continuous

Density Function:

$f(x) = \frac{2(x - \min)}{(\text{m.likely} - \min)(\max - \min)}$	$\min \leq x \leq \text{m.likely}$
$f(x) = \frac{2(\max - x)}{(\max - \text{m.likely})(\max - \min)}$	$\text{m.likely} \leq x \leq \max$

Cumulative Distribution Function:

$F(x) = \frac{(x - \min)^2}{(\text{m.likely} - \min)(\max - \min)}$	$\min \leq x \leq \text{m.likely}$
$F(x) = 1 - \frac{(\max - x)^2}{(\max - \text{m.likely})(\max - \min)}$	$\text{m.likely} \leq x \leq \max$

Mean: $\frac{\max + \text{m.likely} + \min}{3}$

Variance: $\frac{\max^2 + \text{m.likely}^2 + \min^2 - (\max)(\text{m.likely}) - (\text{m.likely})(\min) - (\max)(\min)}{18}$

Skewness: $\frac{2\sqrt{2}}{5} \frac{f(f^2 - 9)}{(f^2 + 3)^{3/2}}$ where $f \equiv \frac{2(\text{m.likely} - \min)}{\max - \min} - 1$

Kurtosis: 2.4

Mode: m. likely

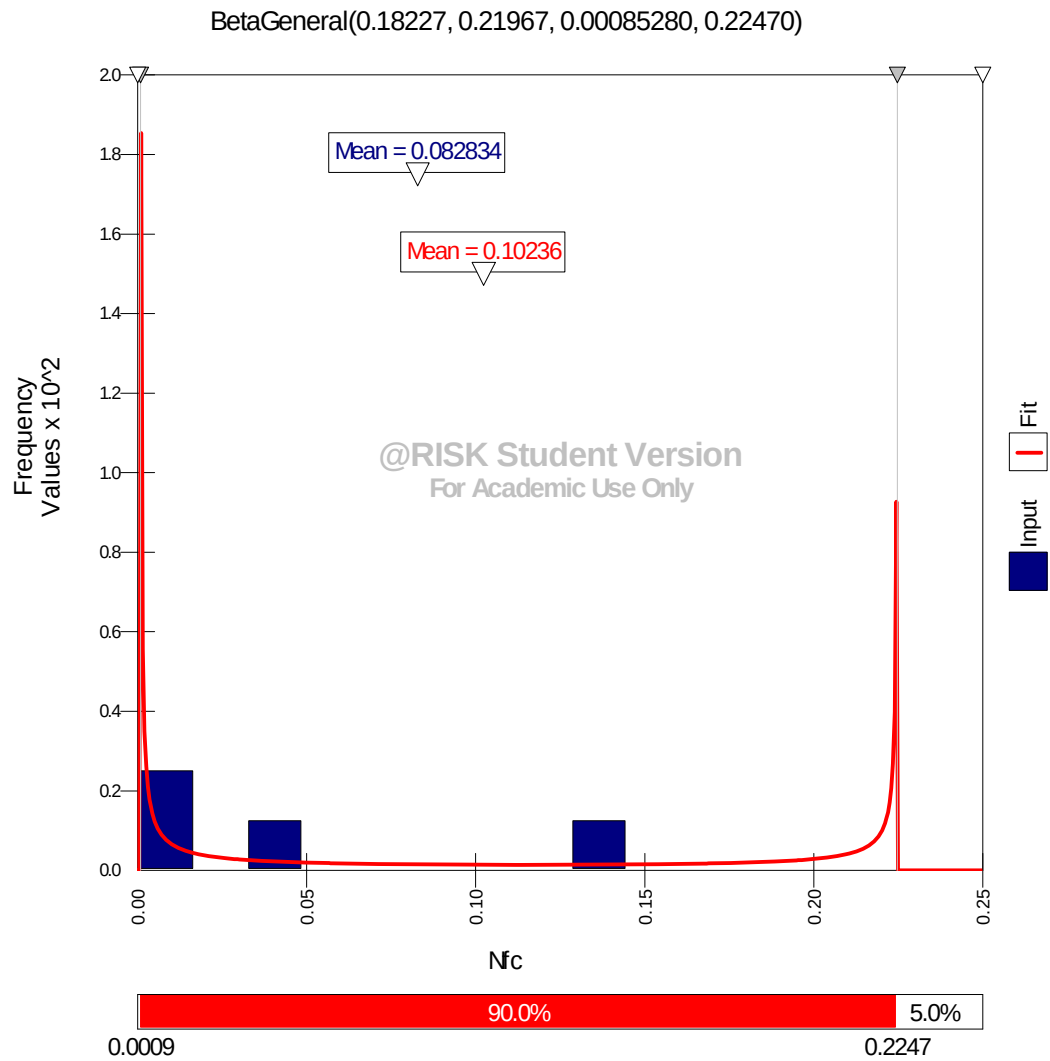


Figure D.2.1 Furnish Formwork, Rebar and Concrete Based on Cost

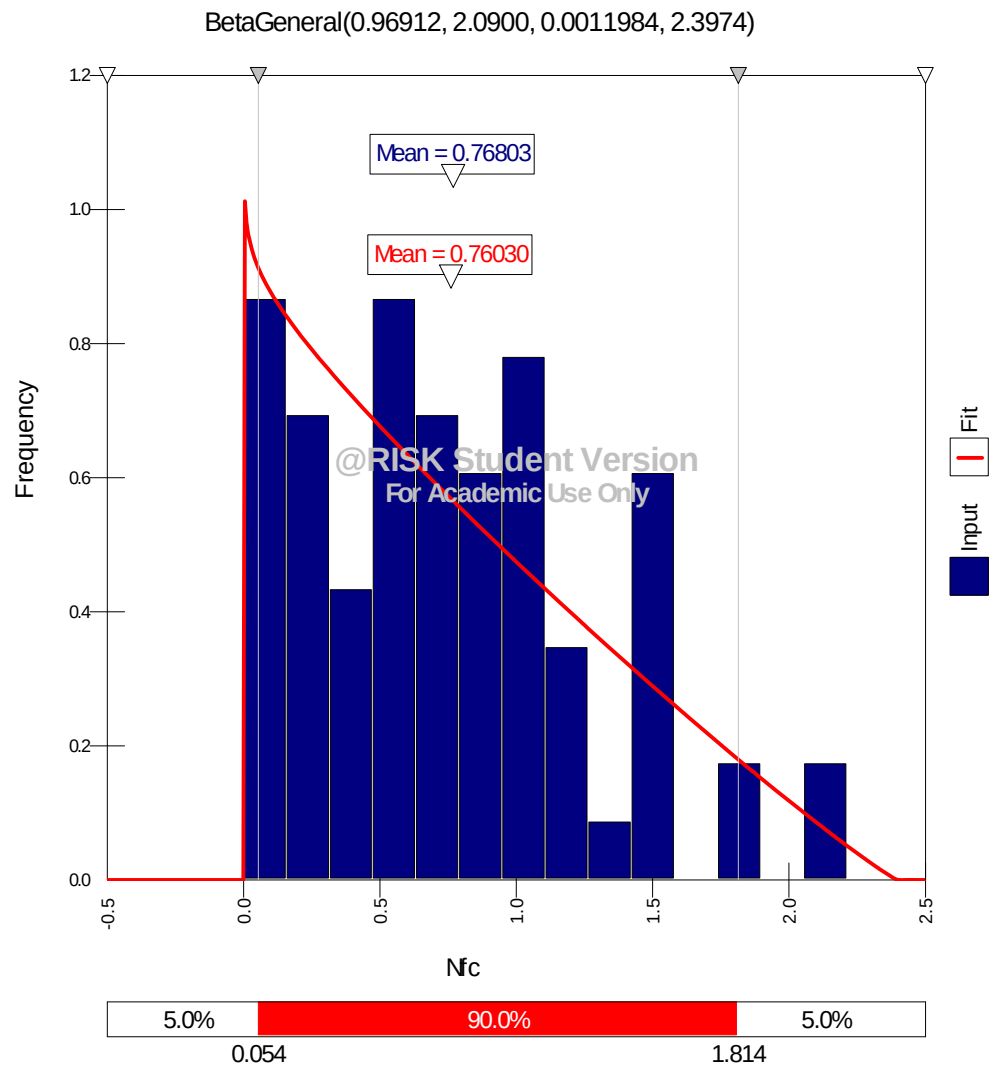


Figure D.2.2 Install Formwork Based on Cost

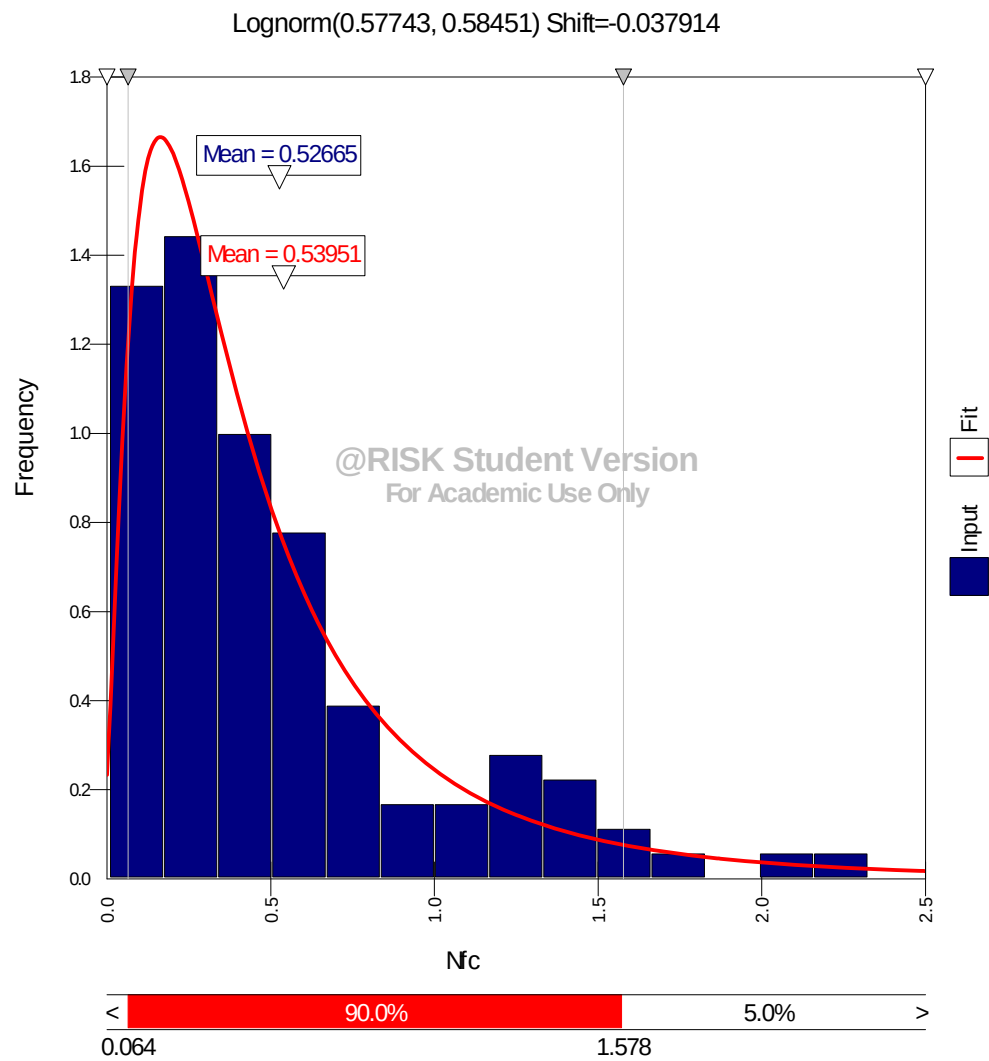


Figure D.2.3 Install Rebar Based on Cost

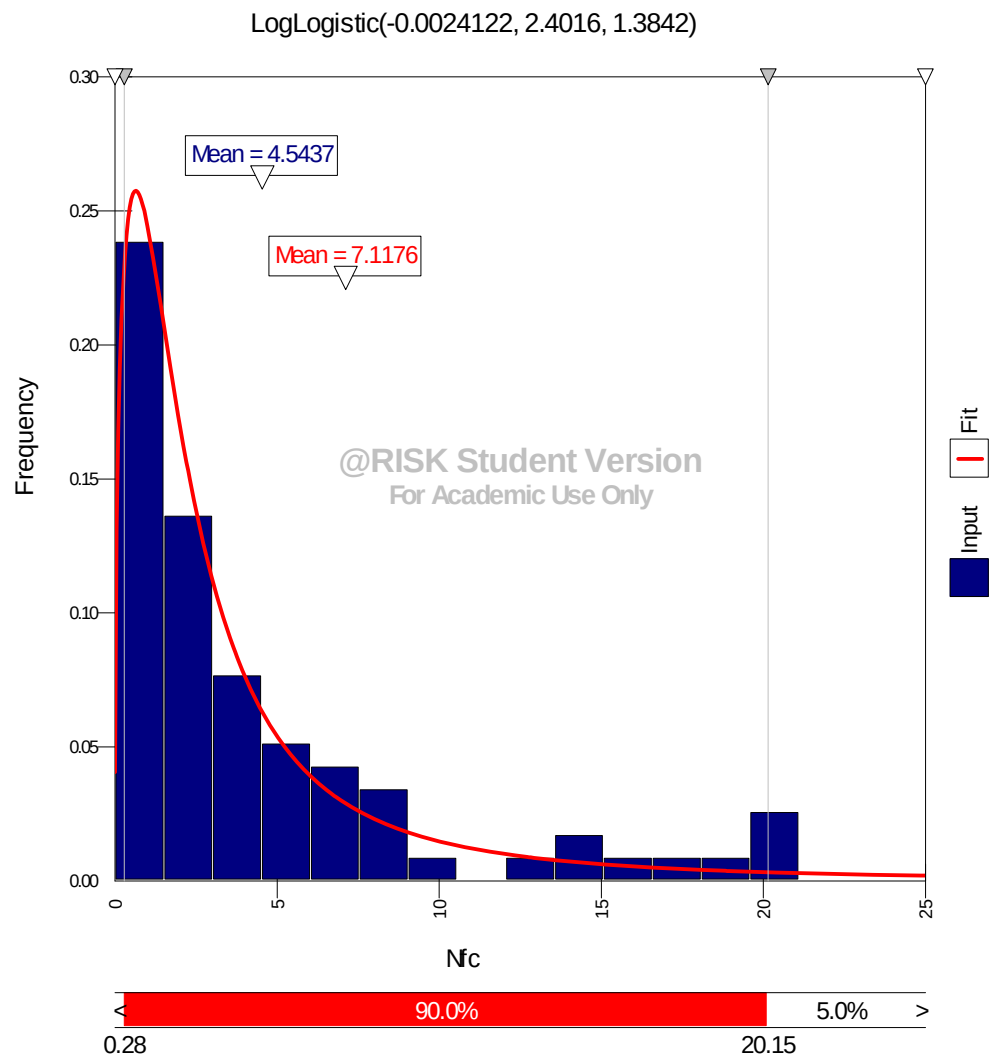


Figure D.2.4 Pour Concrete Based on Cost

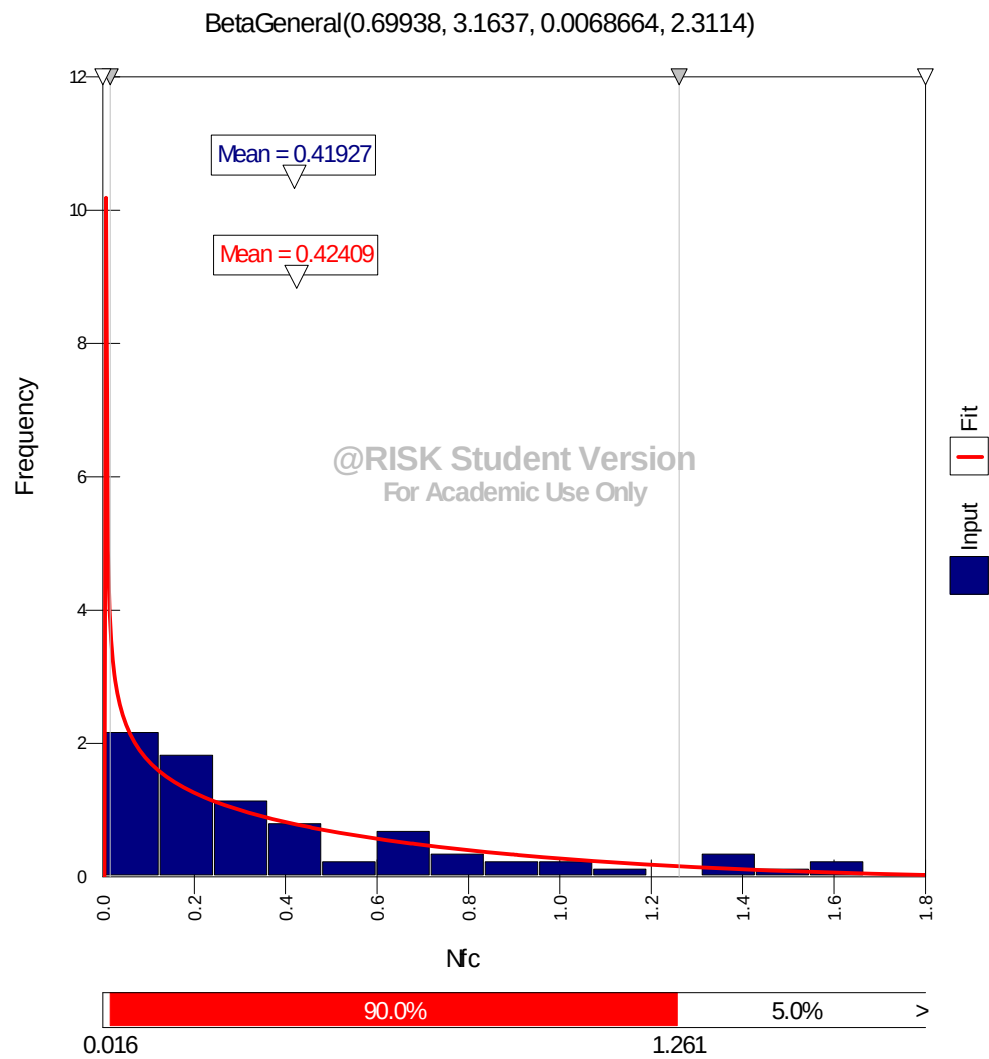


Figure D.2.5 Finish Concrete Based on Cost

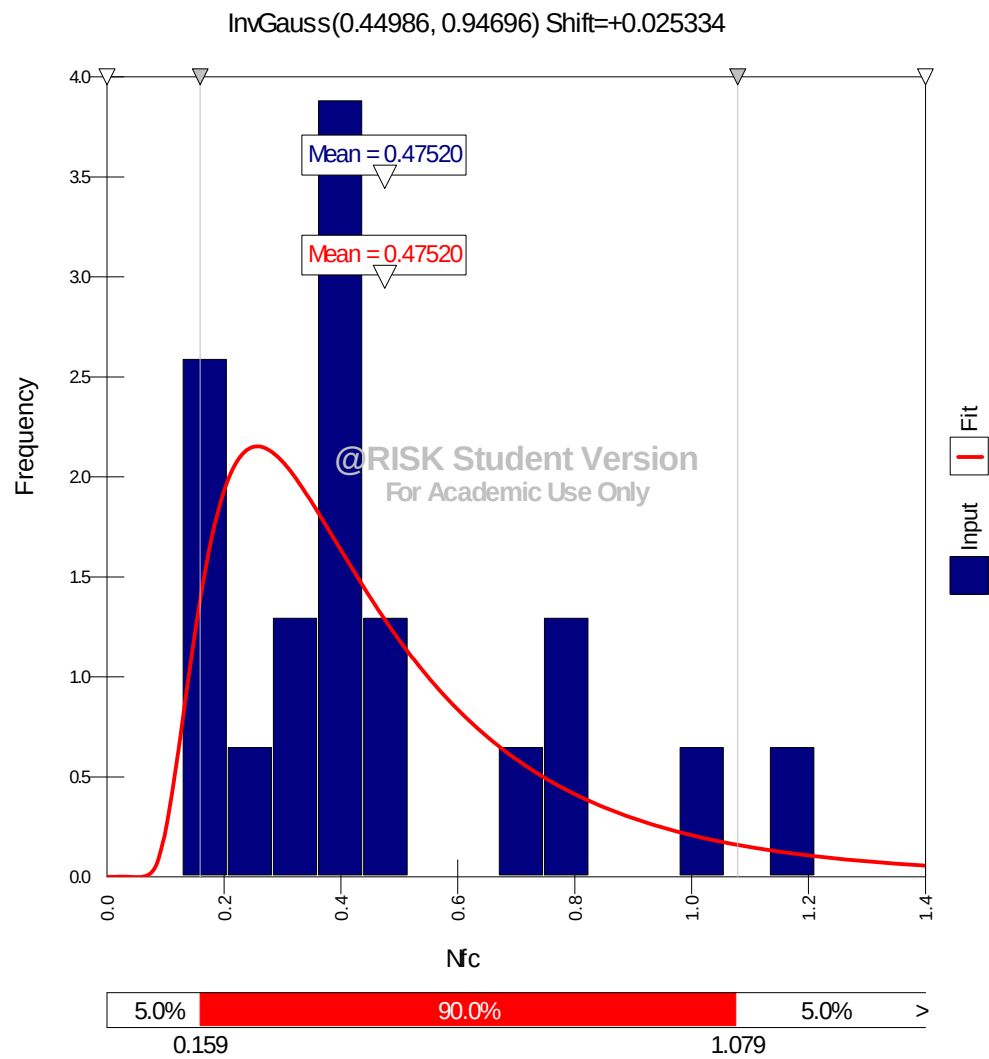


Figure D.2.6 Furnish & Install Grout Based on Cost

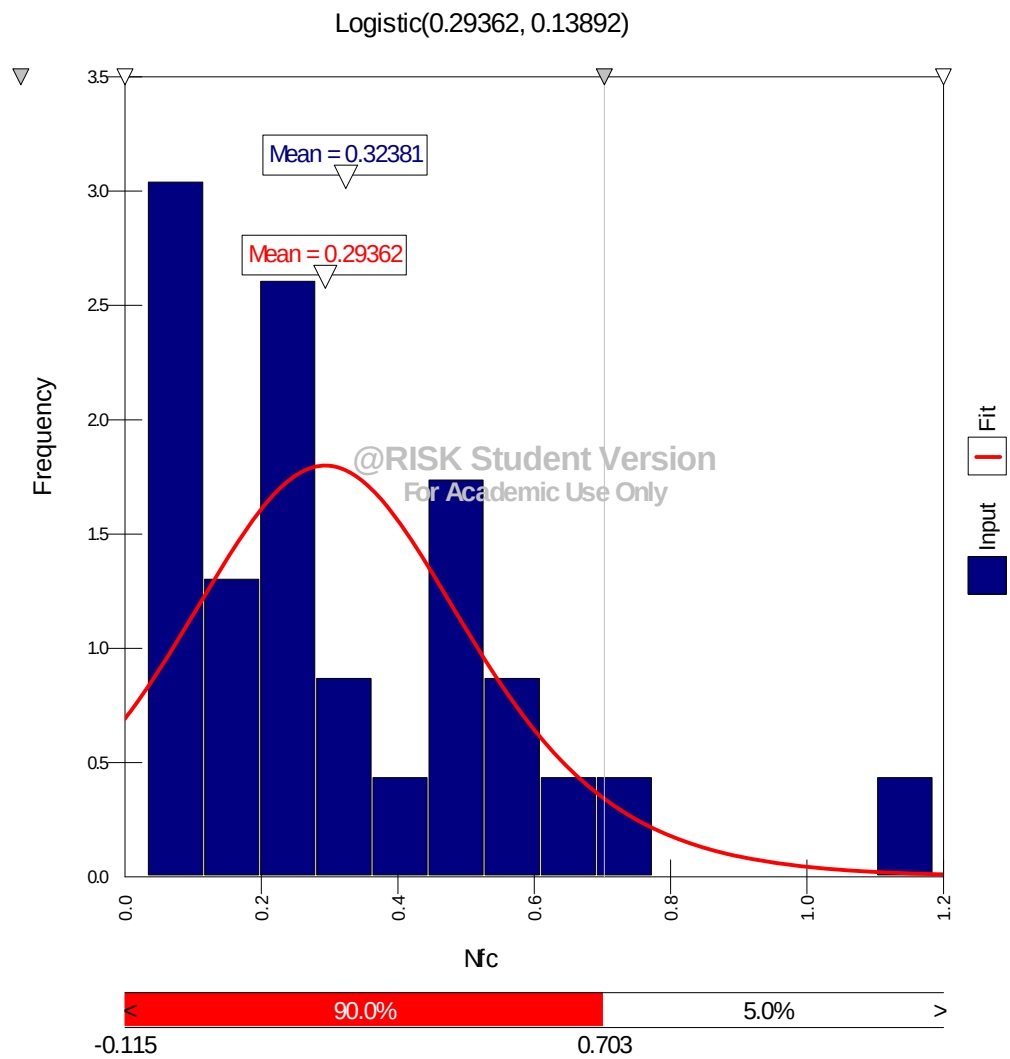


Figure D.2.7 Excavation Based on Cost

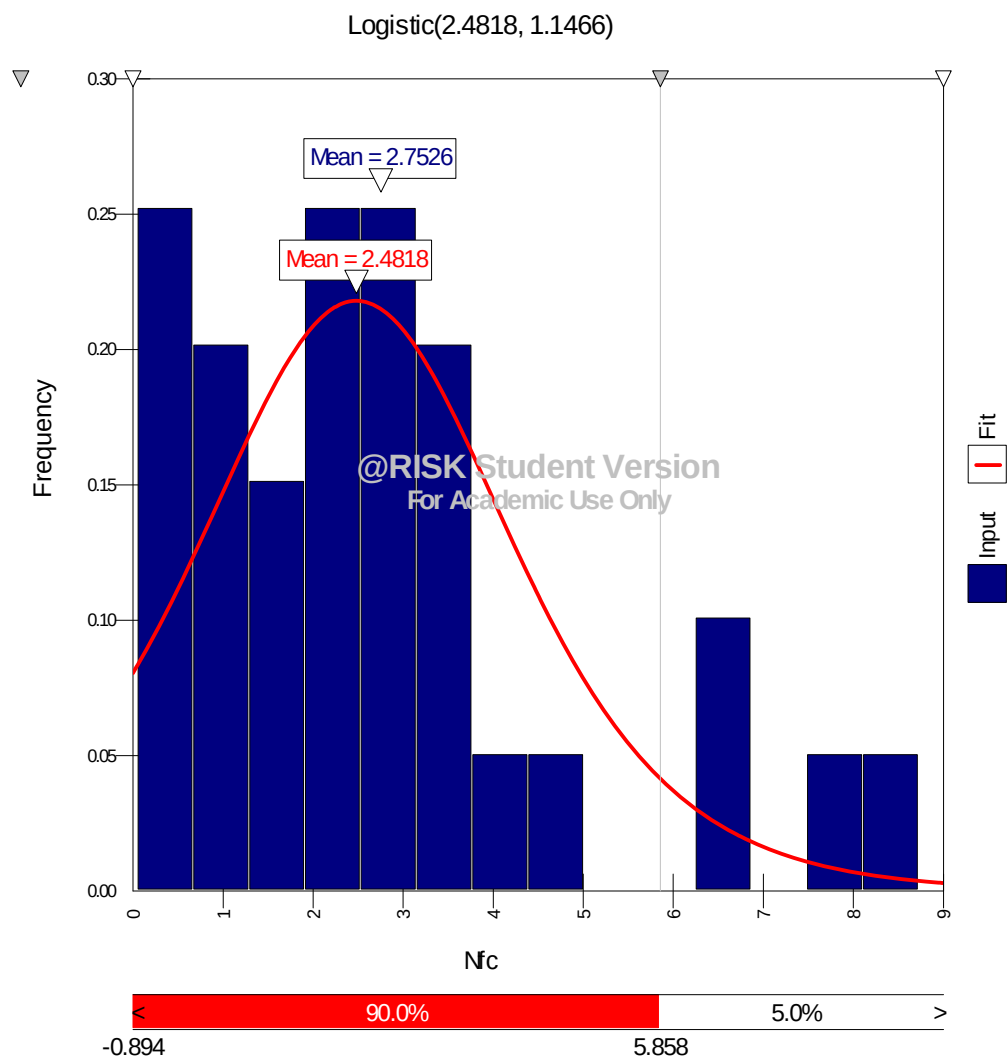


Figure D.2.8 Place Fills Based on Cost

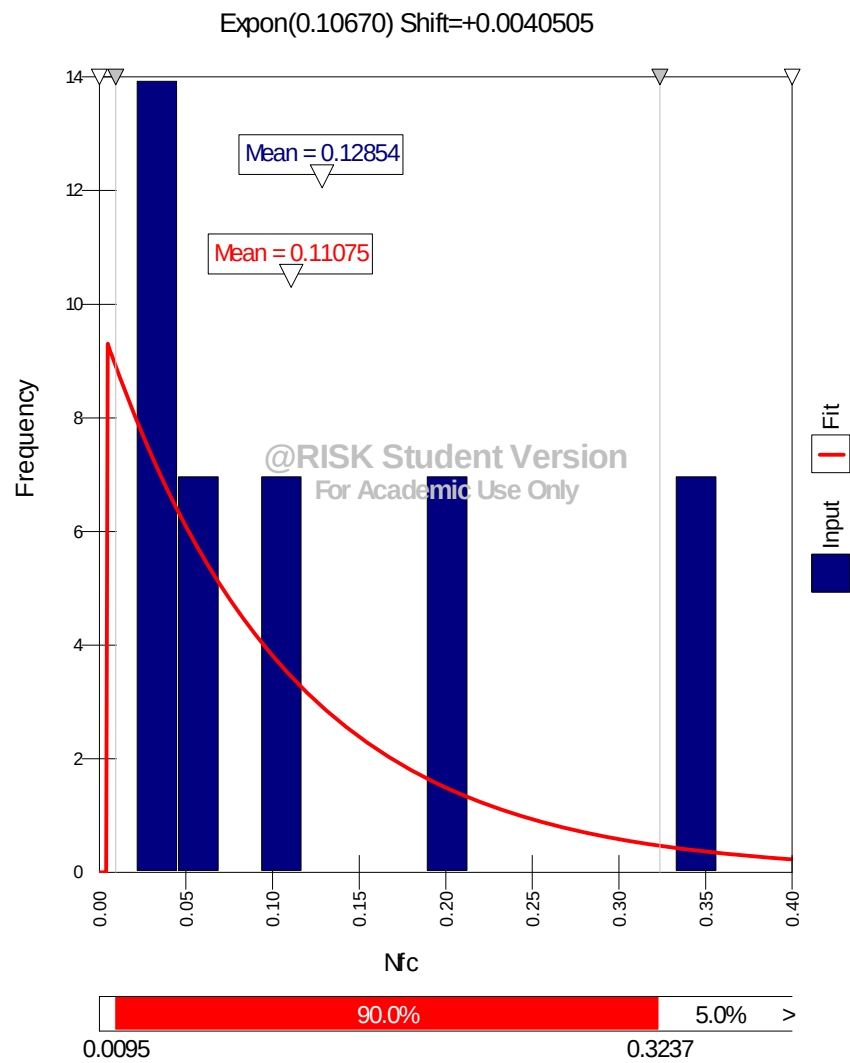


Figure D.2.9 Change Orders Based on Cost

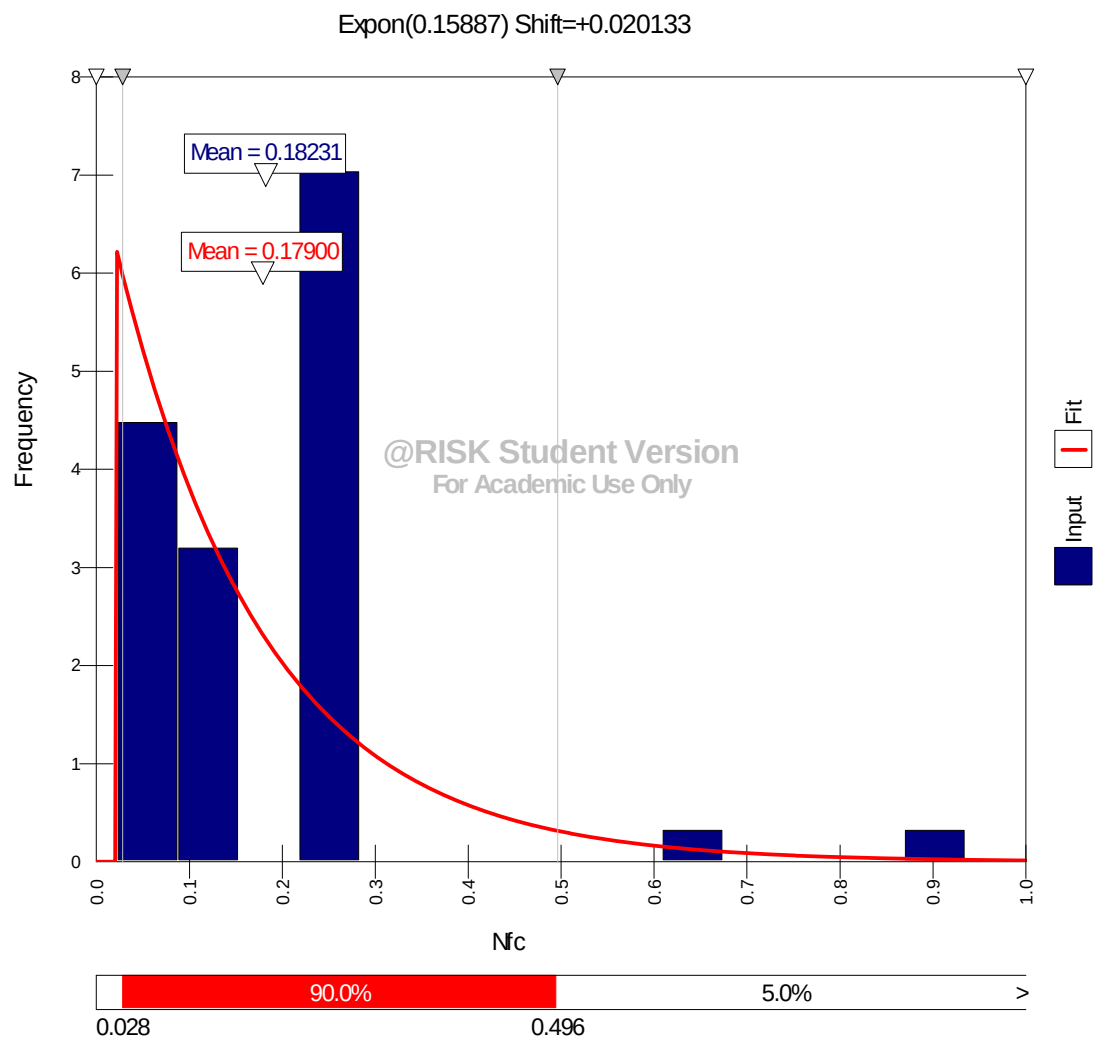


Figure D.2.10 Unit Prices Based on Cost

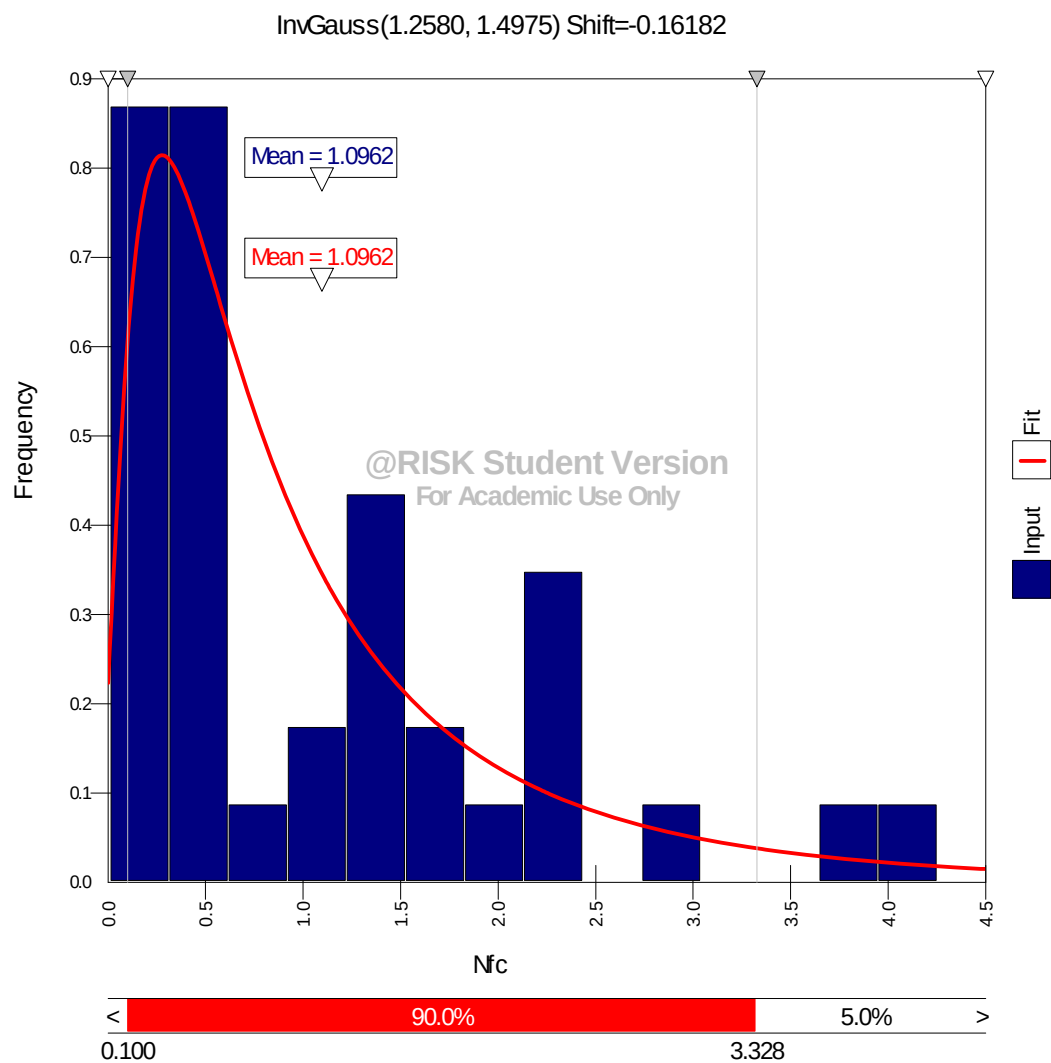


Figure D.2.11 Cut-Off, Haul & Dispose Piles Based on Cost

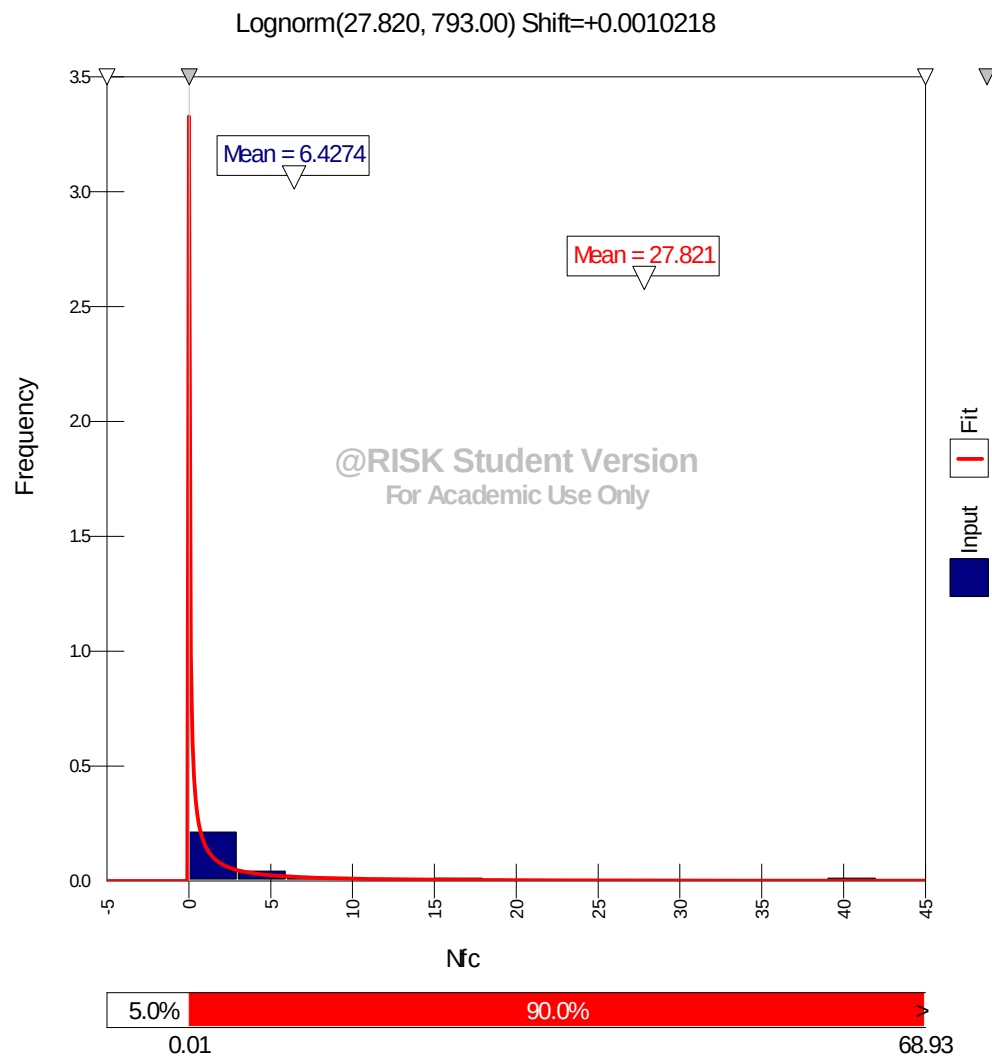


Figure D.2.12 Concrete Demolition Based on Cost

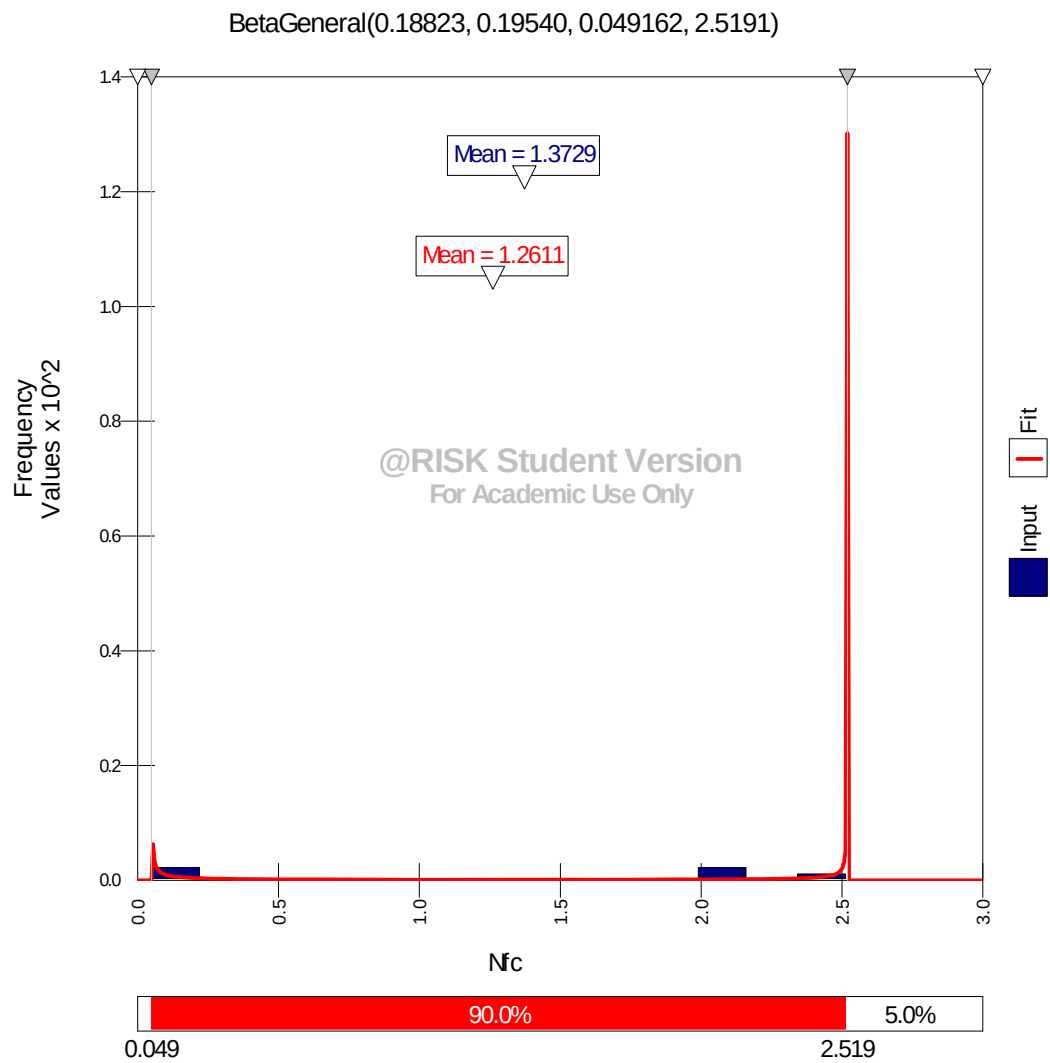


Figure D.2.13 Furnish & Install Structural Steel Based on Cost

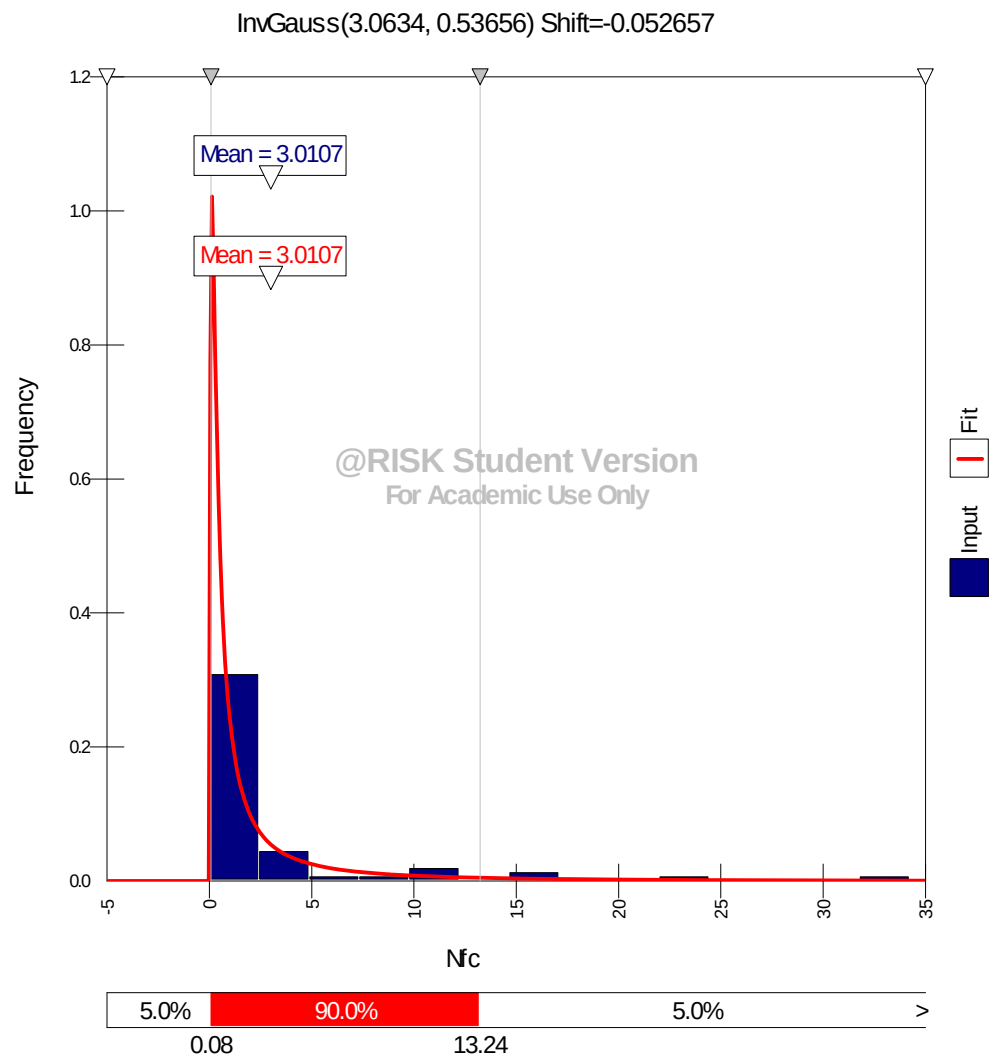


Figure D.2.14 Furnish & Install Miscellaneous Metals Based on Cost

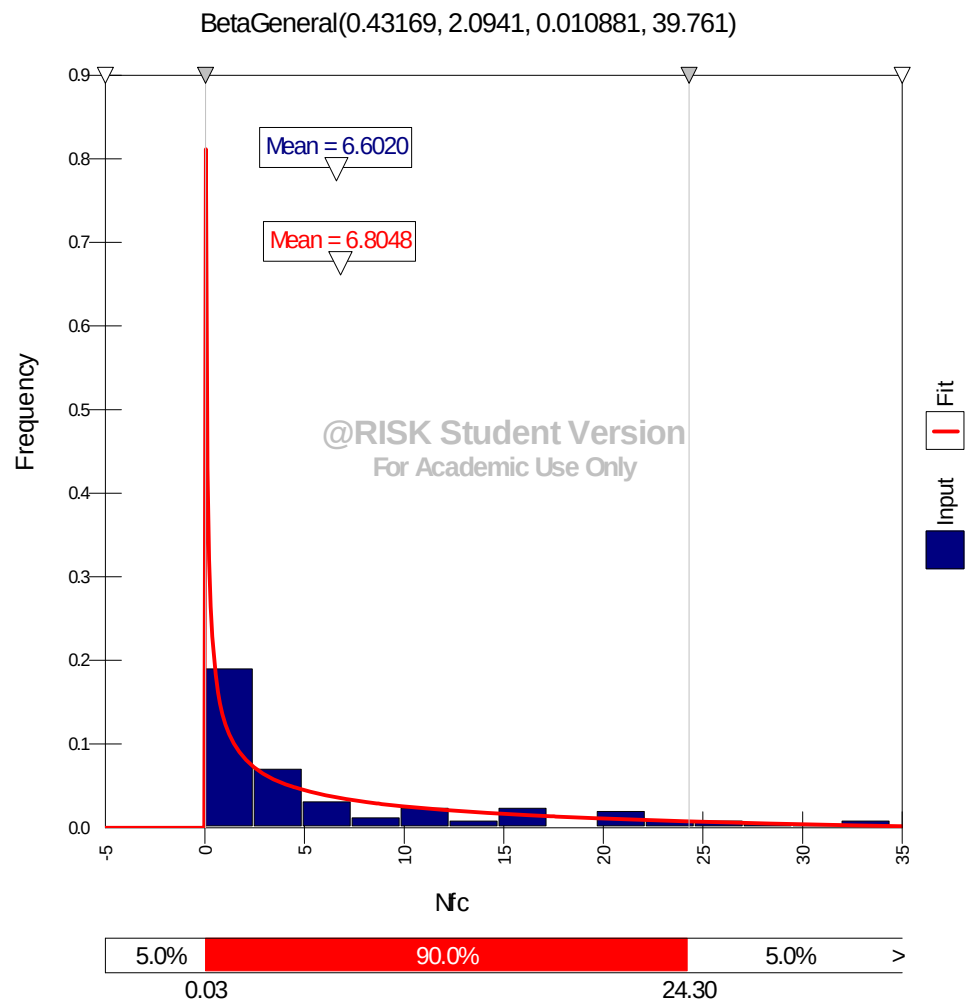


Figure D.2.15 Mechanical Based on Cost

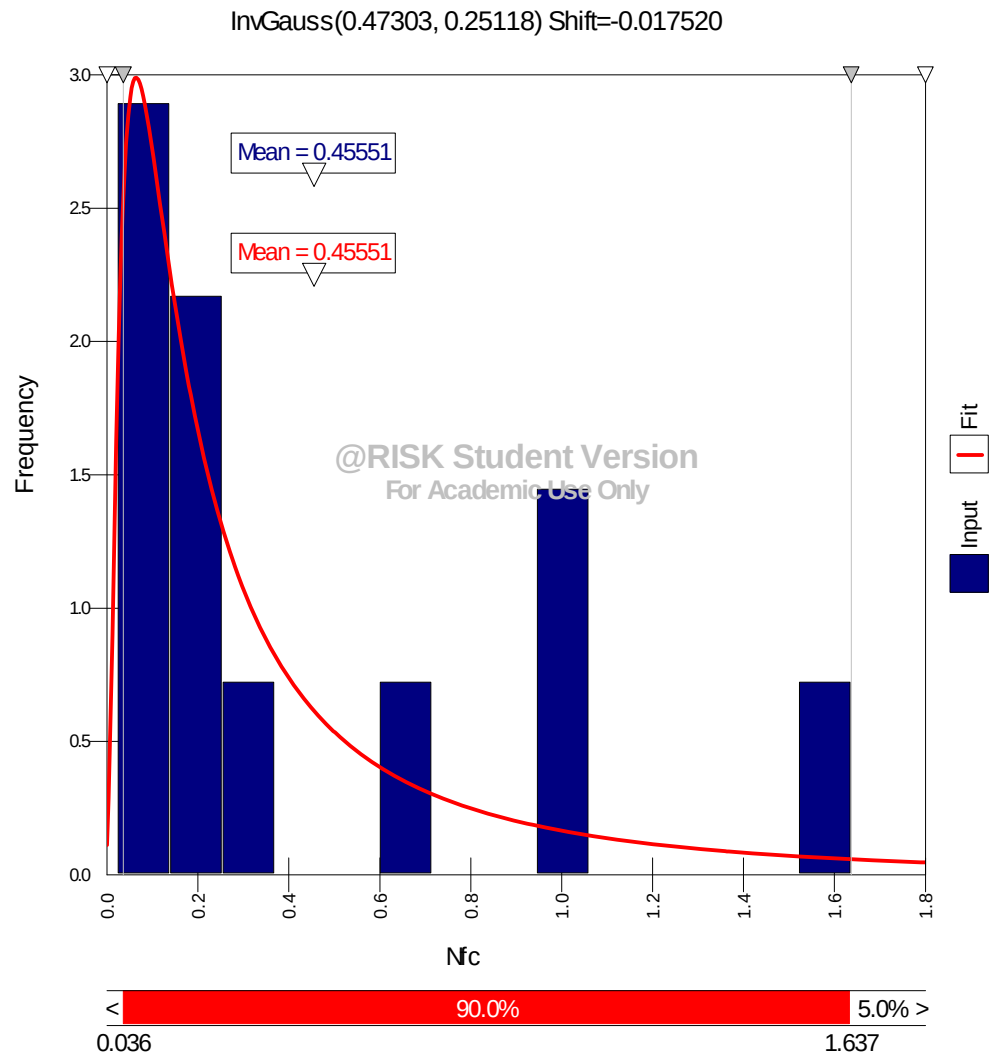


Figure D.2.16 Furnish & Install Pipes & Fittings Based on Cost

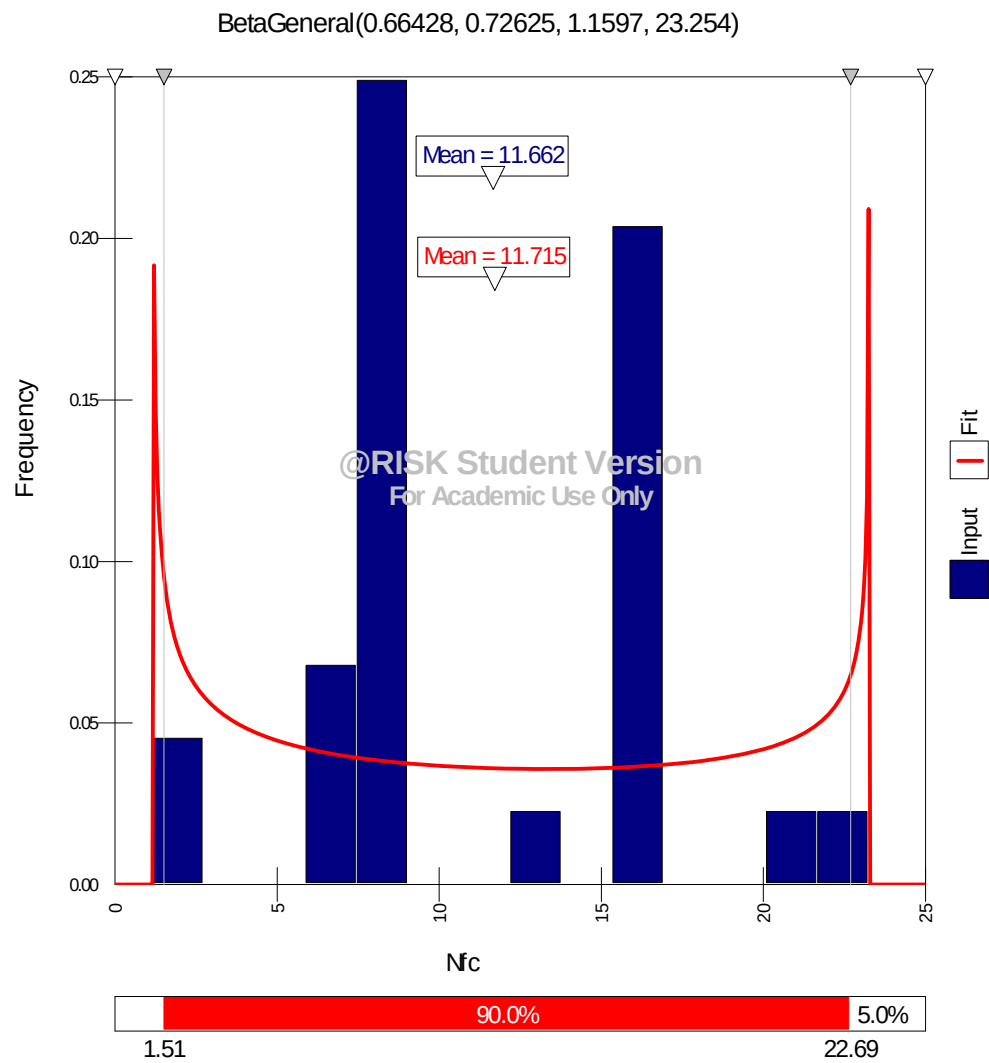


Figure D.2.17 Furnish & Install Thermal and Moist Protection Based on Cost

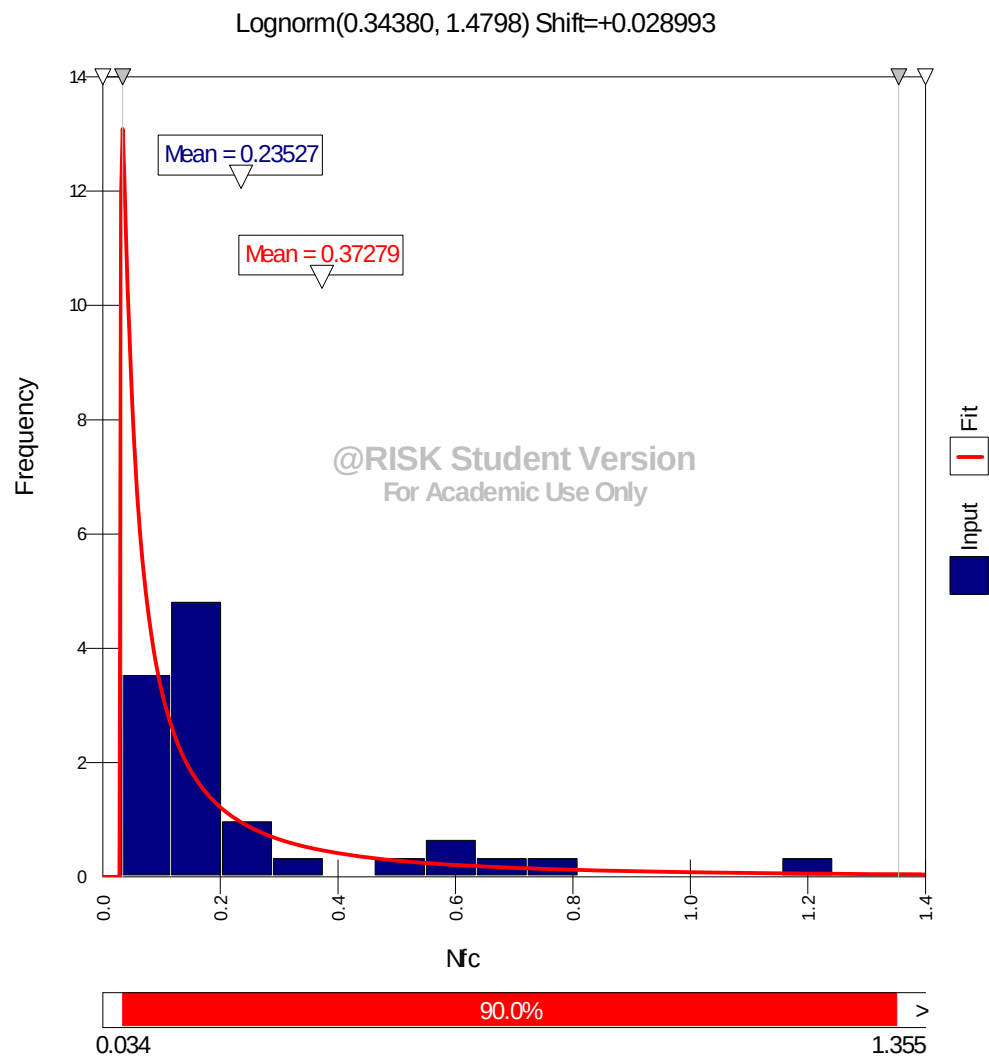


Figure D.2.18 Furnish & Install Doors and Windows Based on Cost

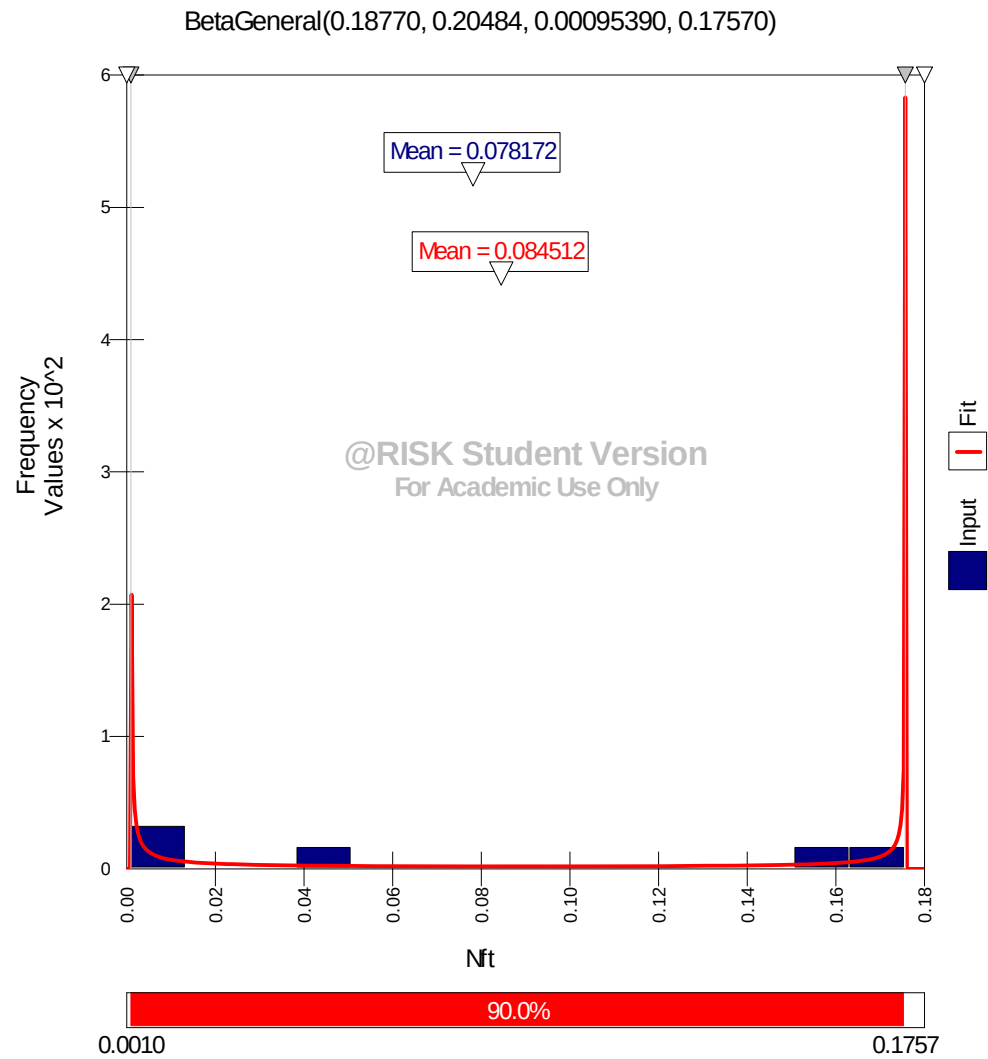


Figure D.3.1 Furnish Formwork, Rebar and Concrete Based on Time

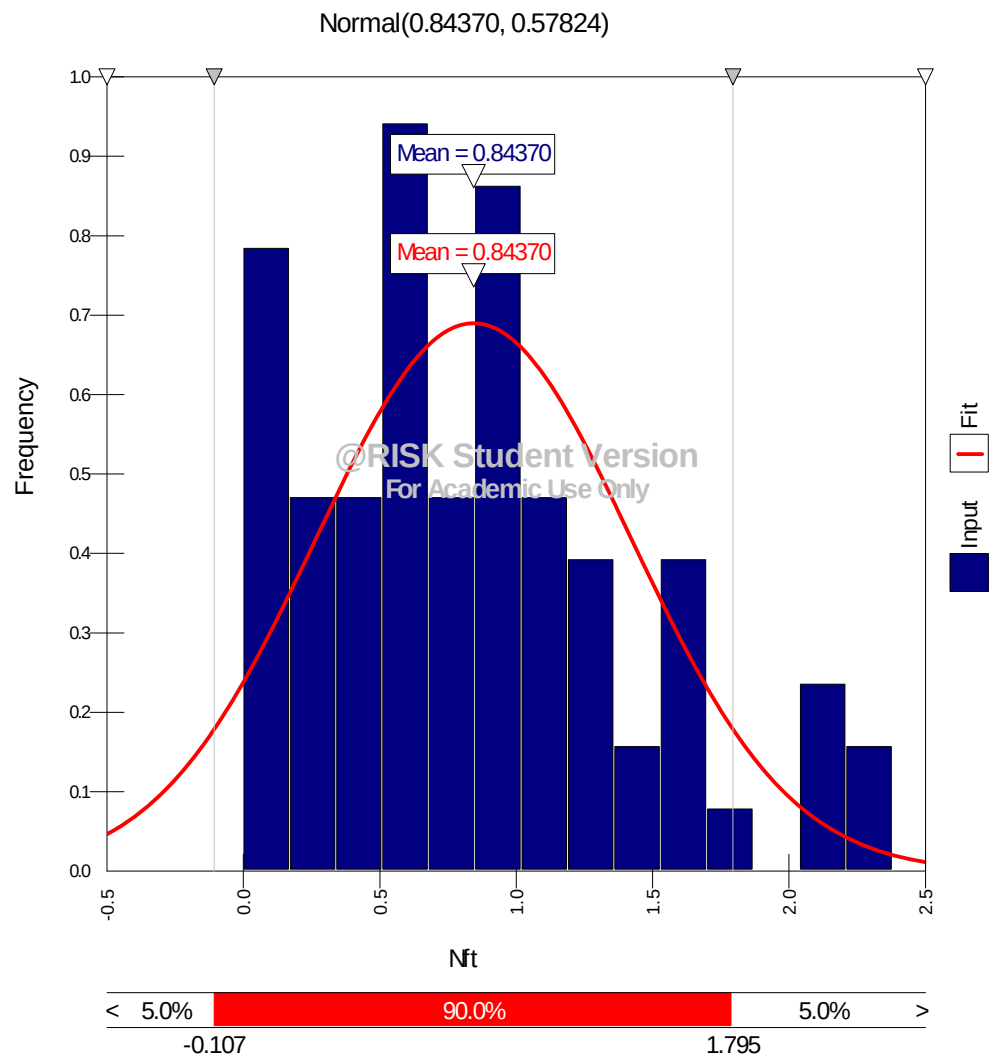


Figure D.3.2 Install Formwork Based on Time

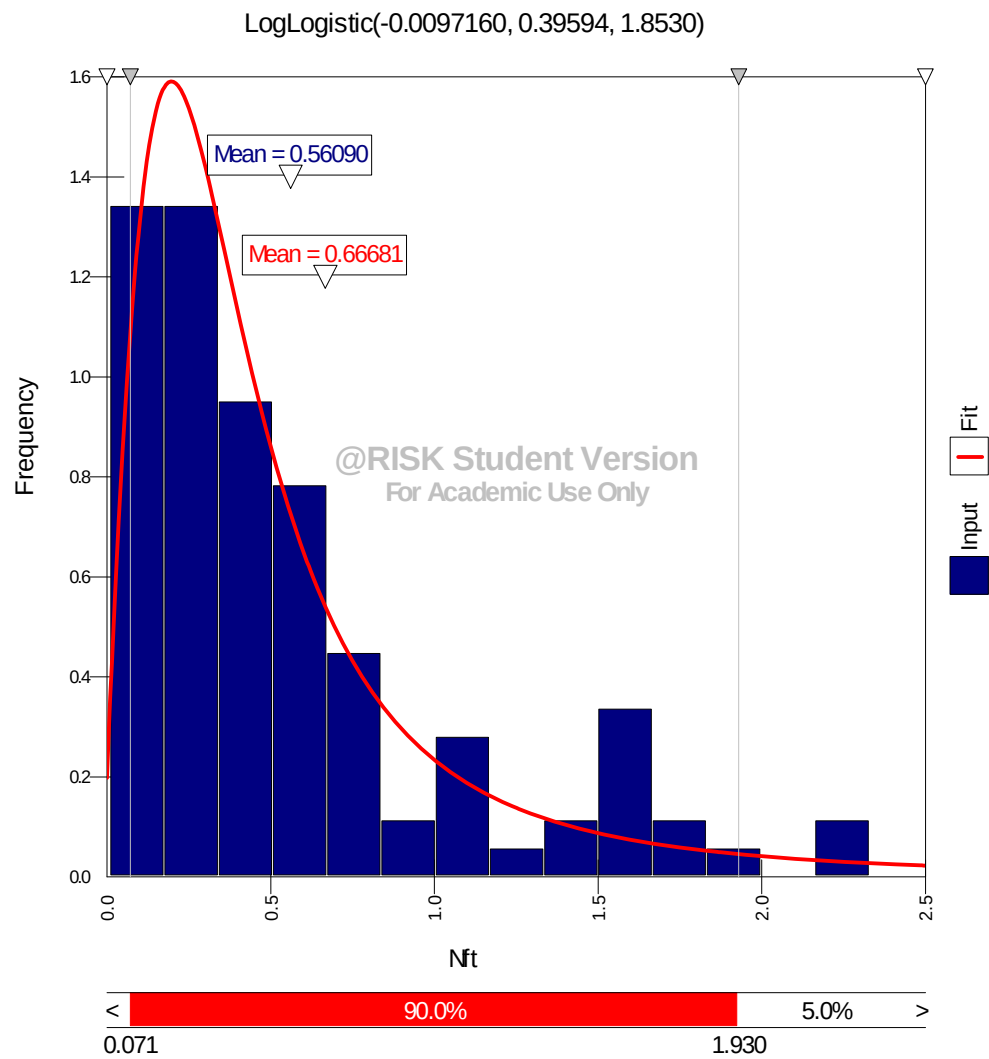


Figure D.3.3 Install Rebar Based on Time

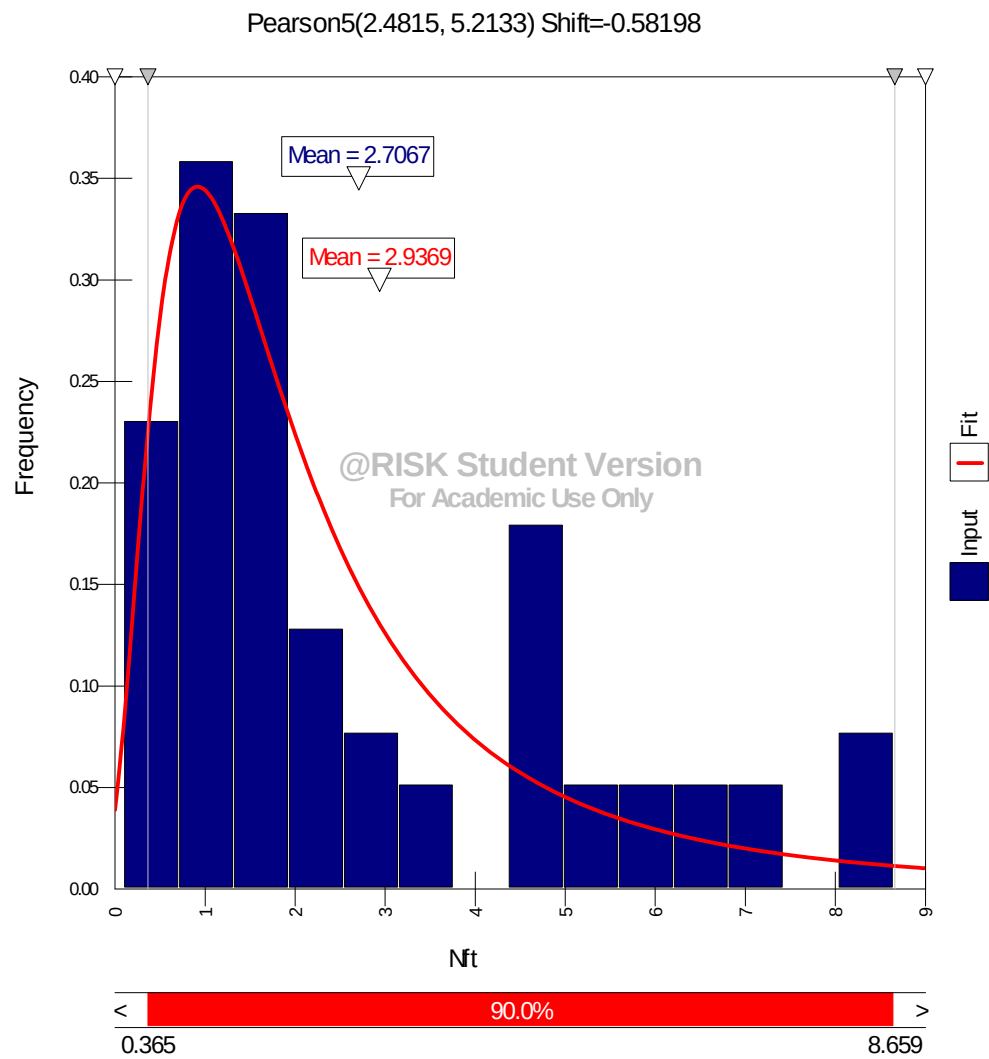


Figure D.3.4 Pour Concrete Based on Time

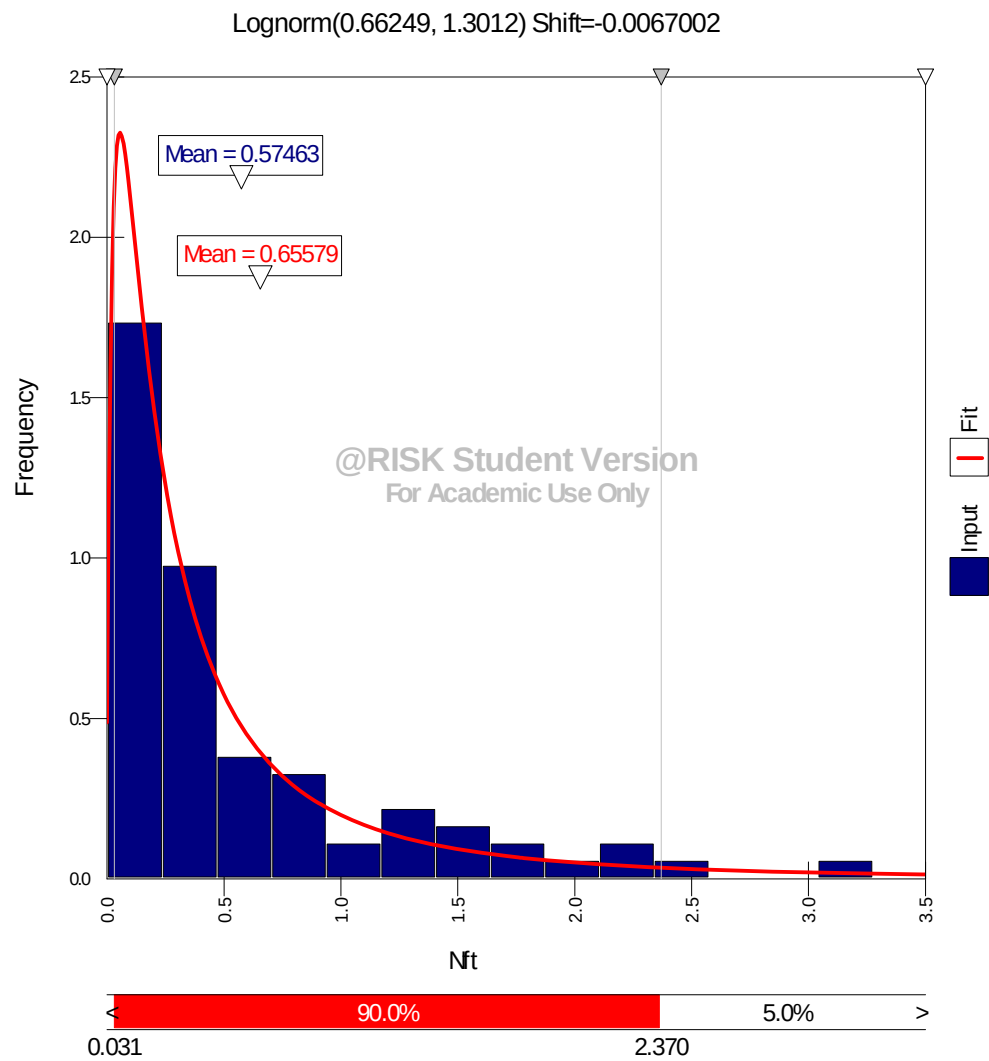


Figure D.3.5 Finish Concrete Based on Time

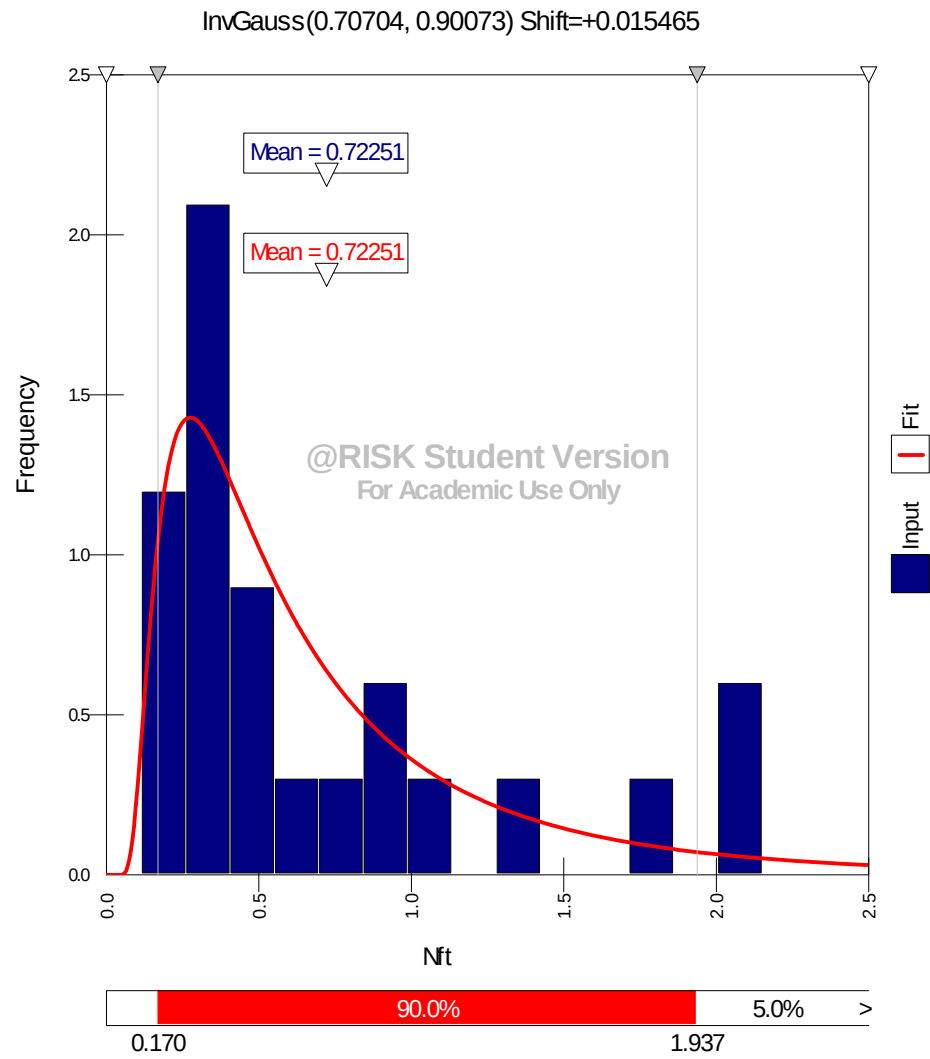


Figure D.3.6 Furnish & Install Grout Based on Time

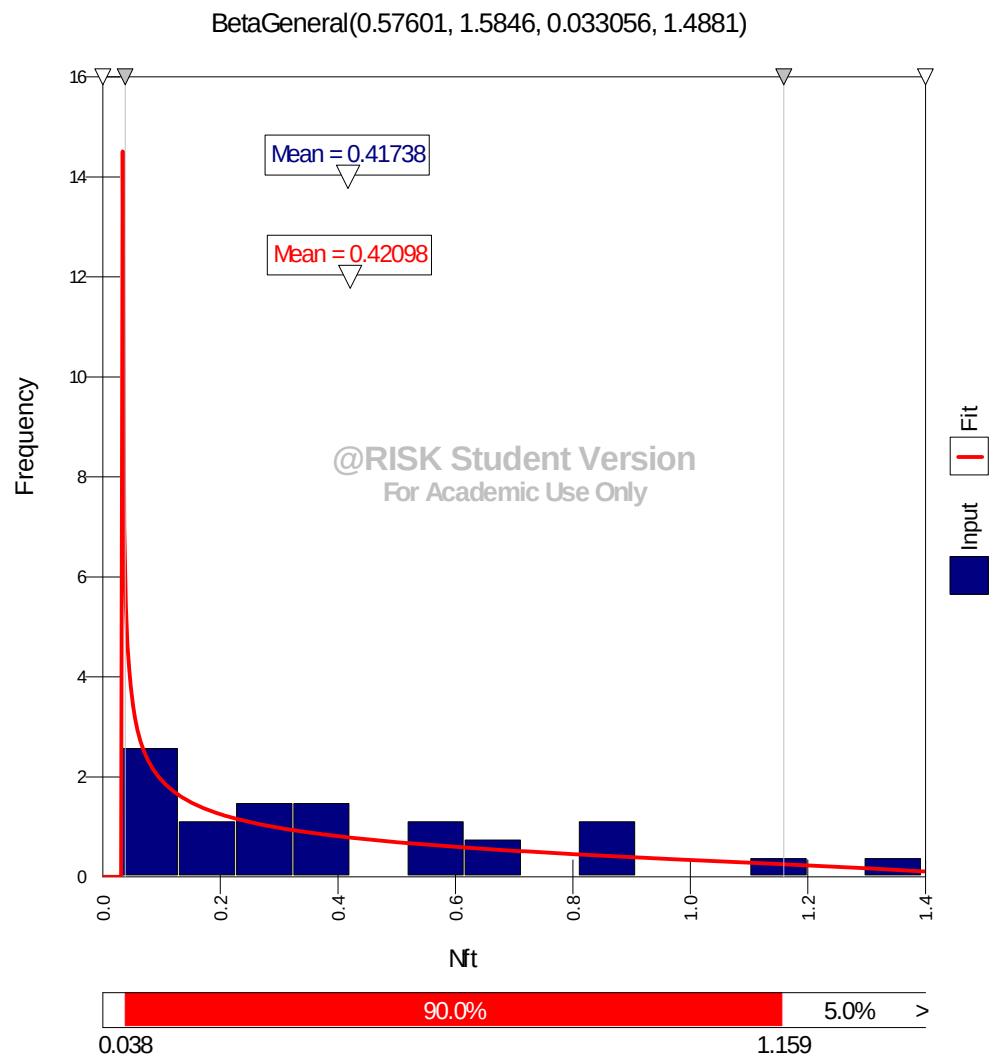


Figure D.3.7 Excavation Based on Time

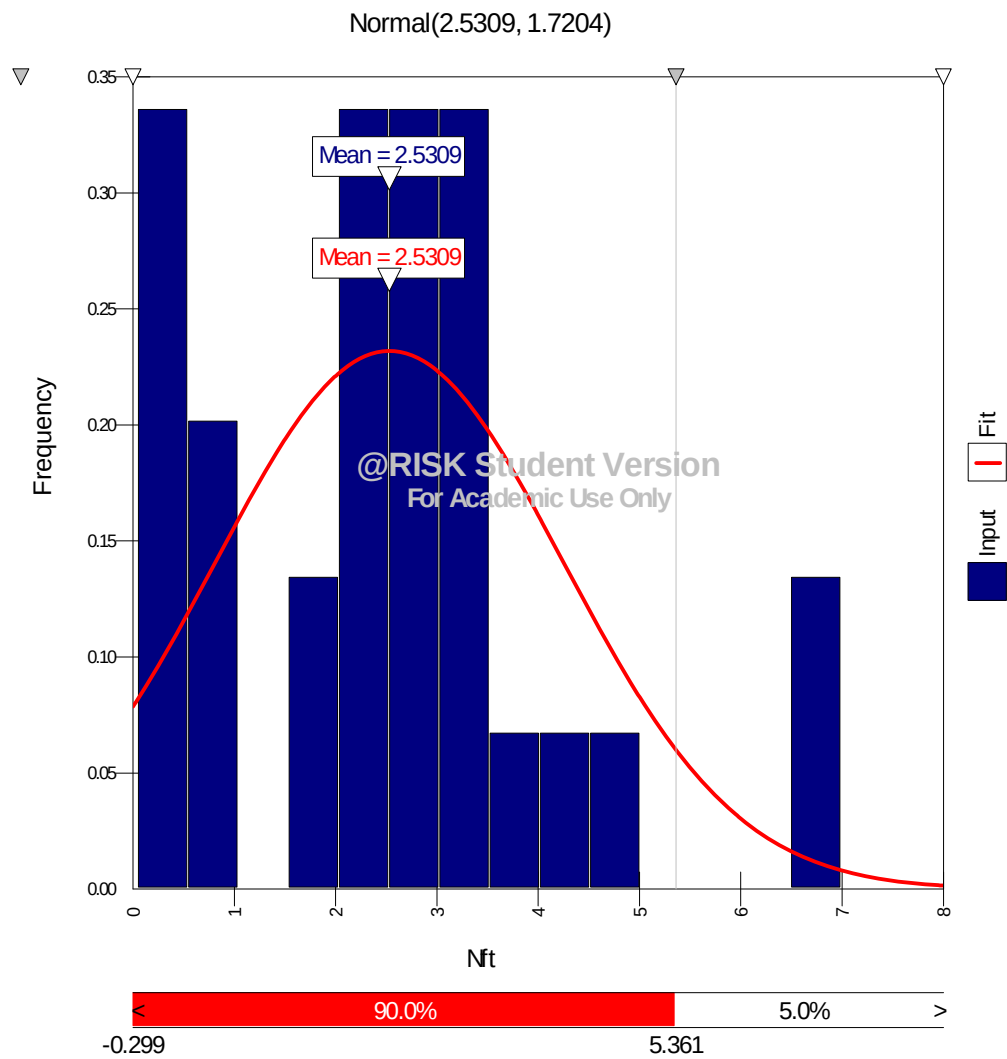


Figure D.3.8 Place Fill Based on Time

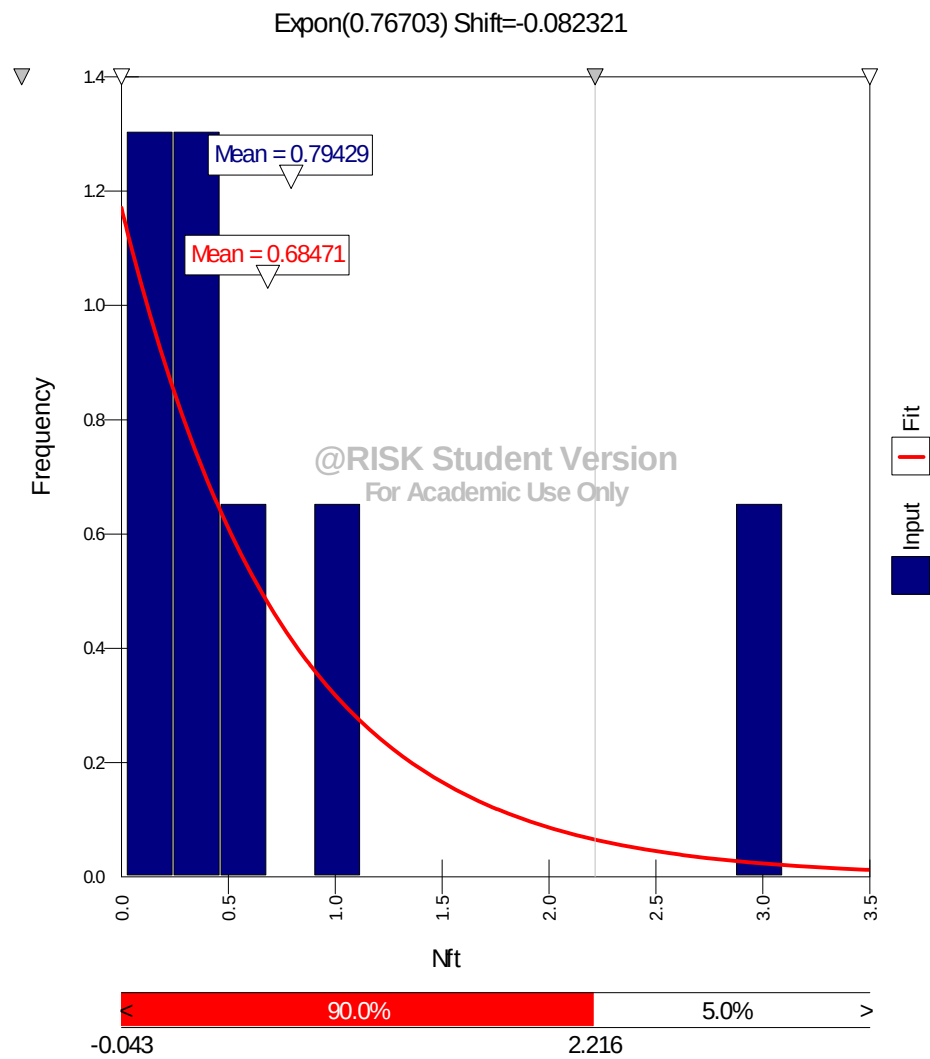


Figure D.3.9 Change Orders Based on Time

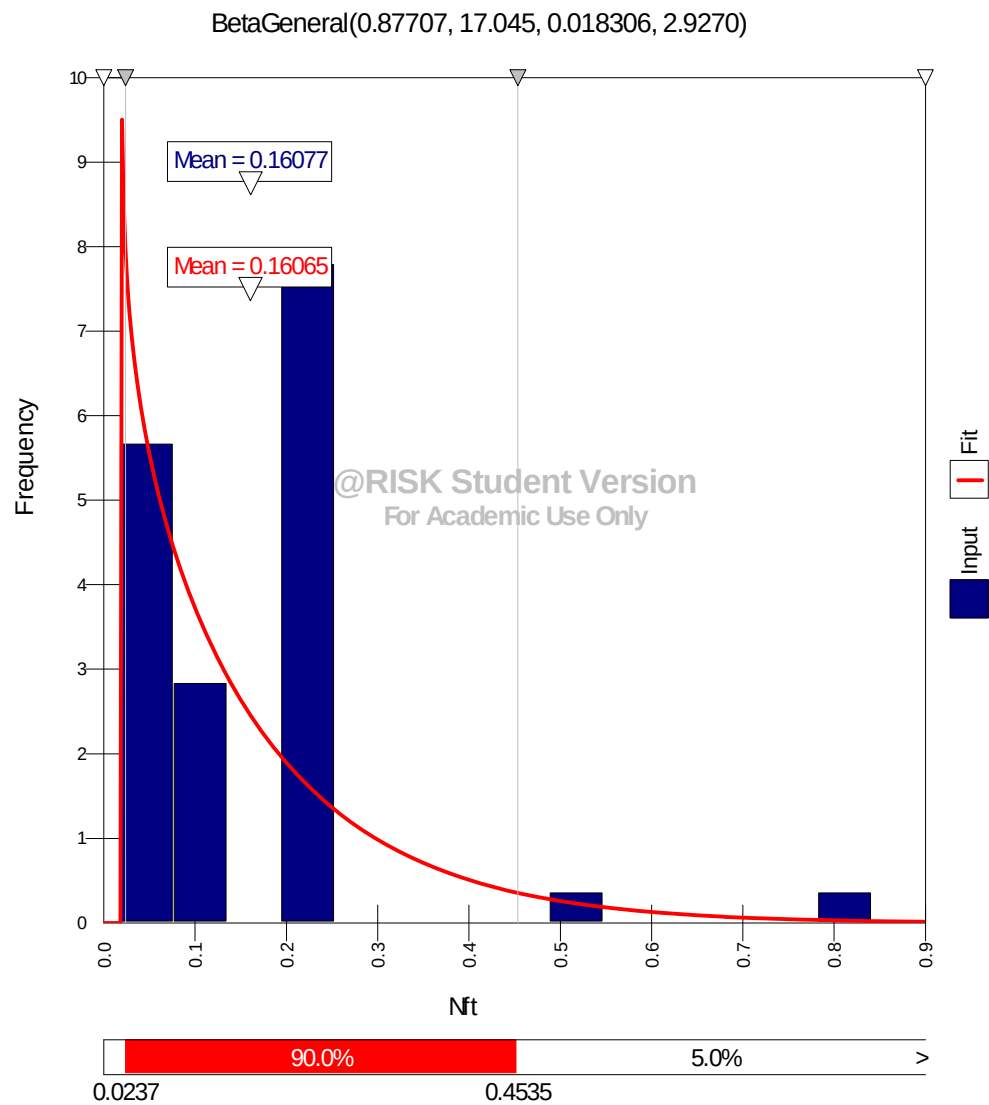


Figure D.3.10 Unit Prices Based on Time

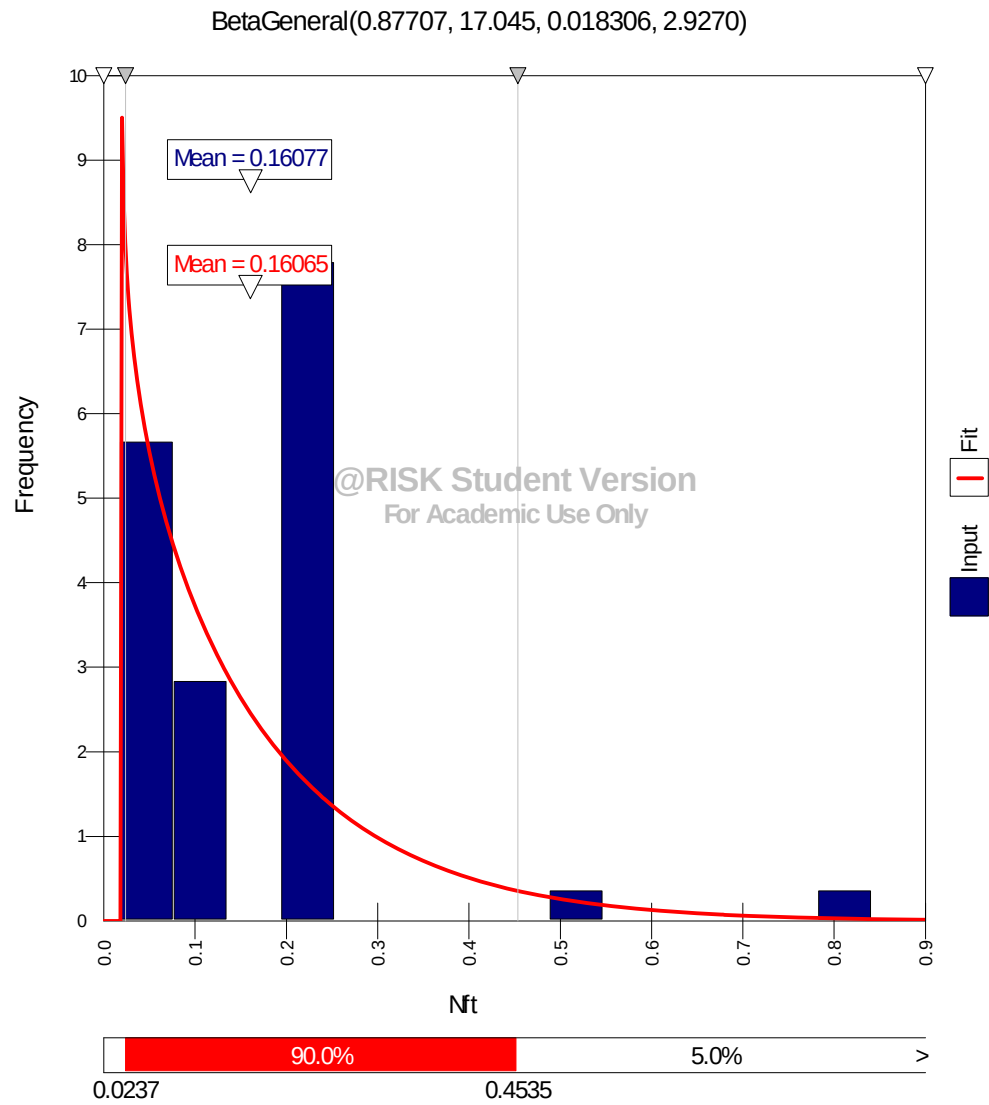


Figure D.3.11 Cut-Off, Haul & Dispose Piles Based on Time

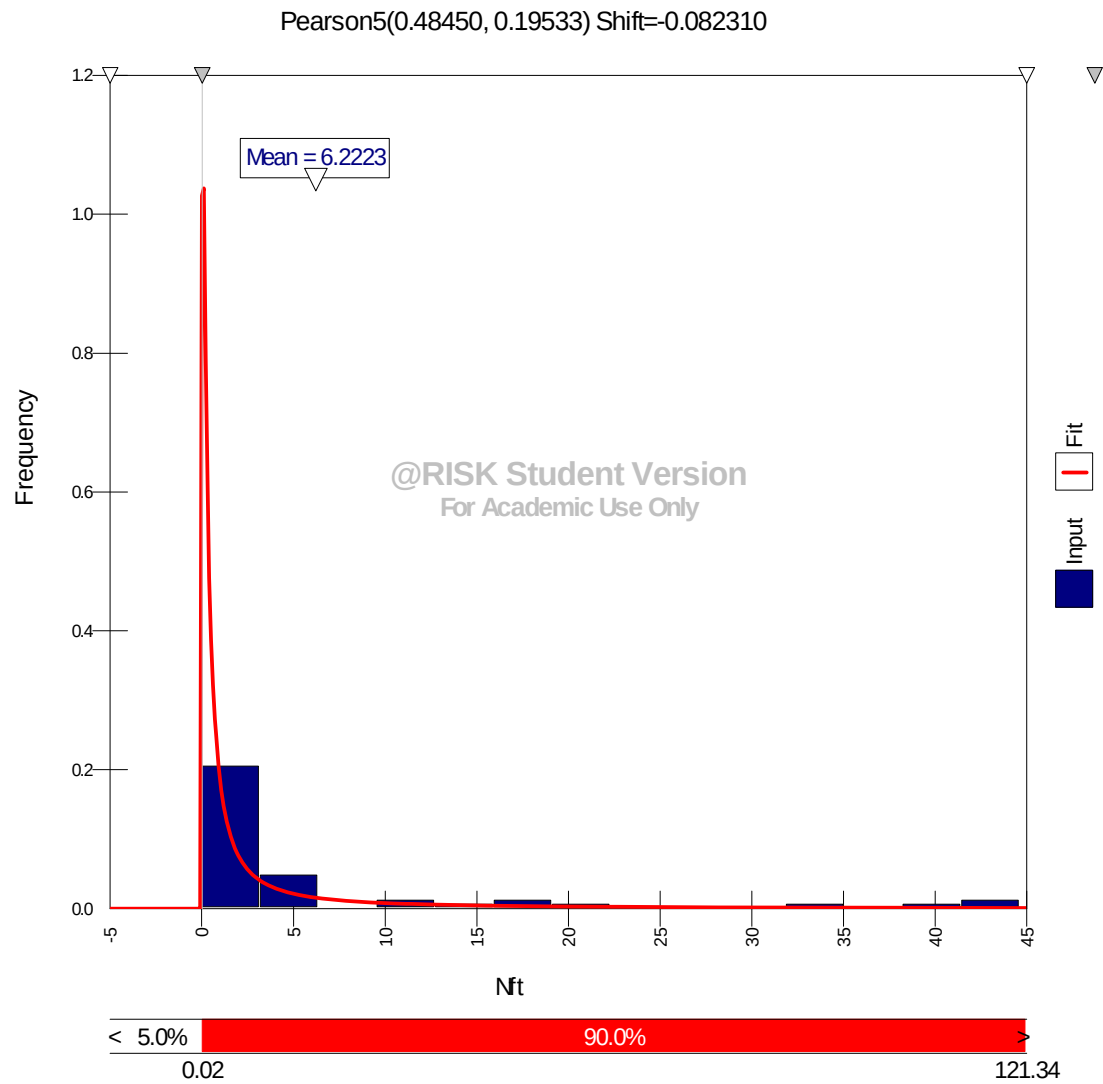


Figure D.3.12 Concrete Demolition Based on Time

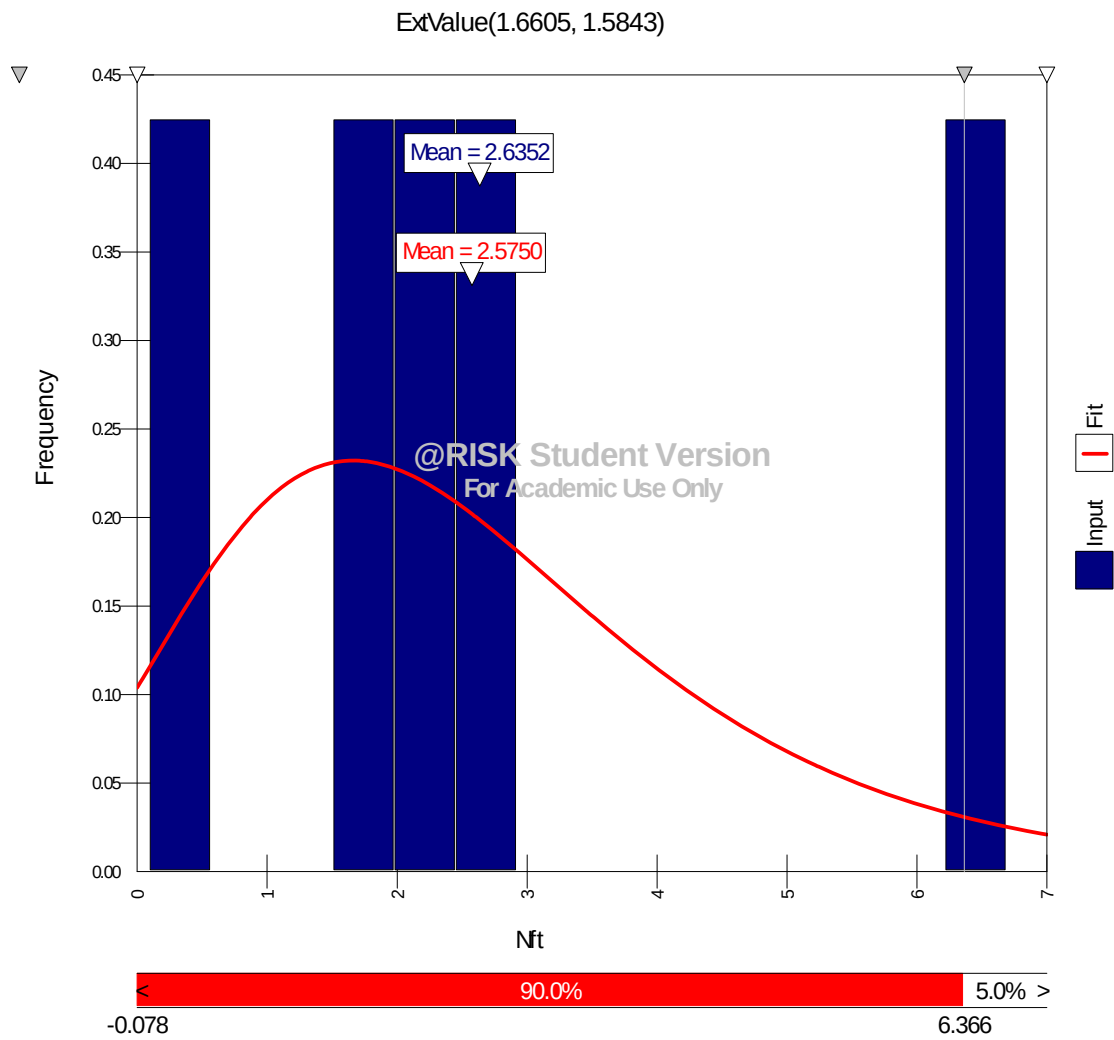


Figure D.3.13 Furnish & Install Structural Steel Based on Time

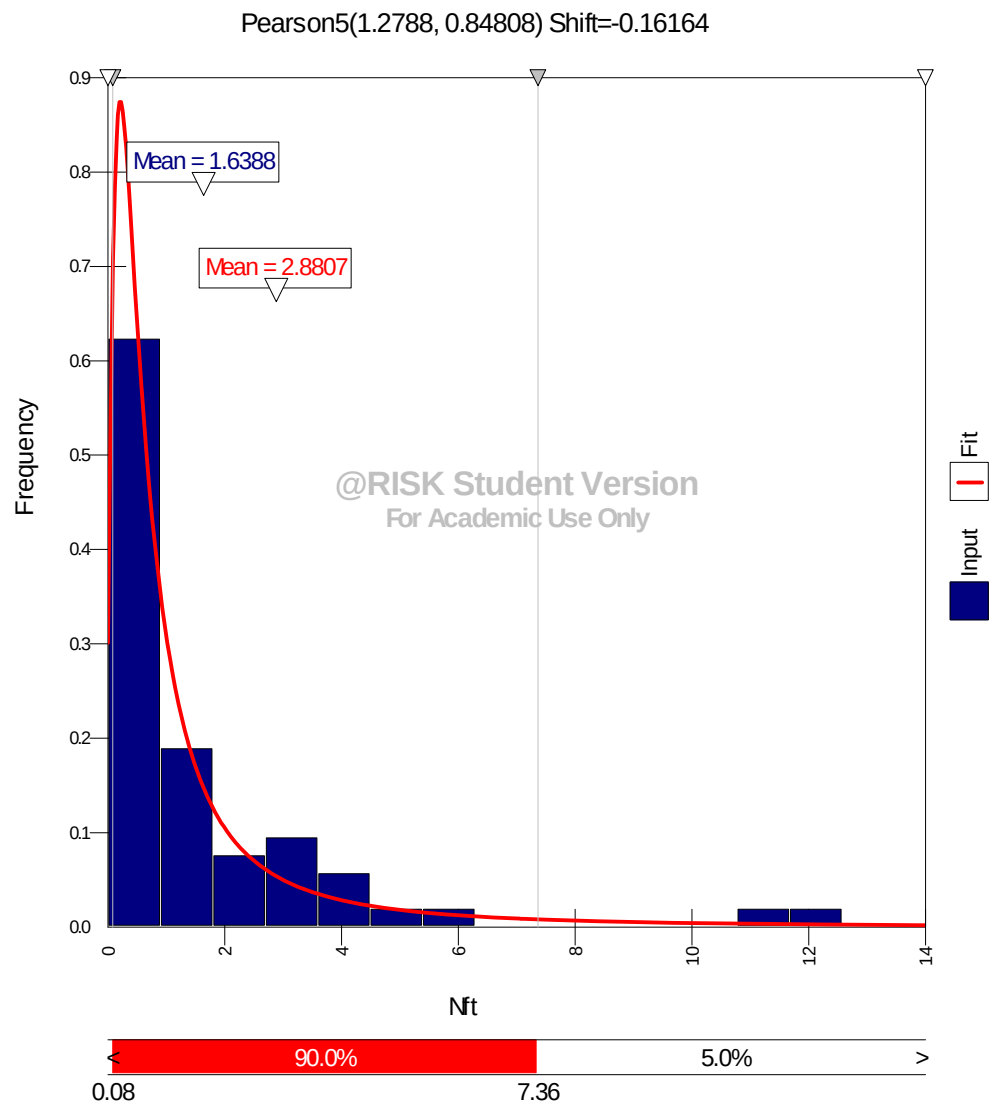


Figure D.3.14 Furnish & Install Miscellaneous Metal Based on Time

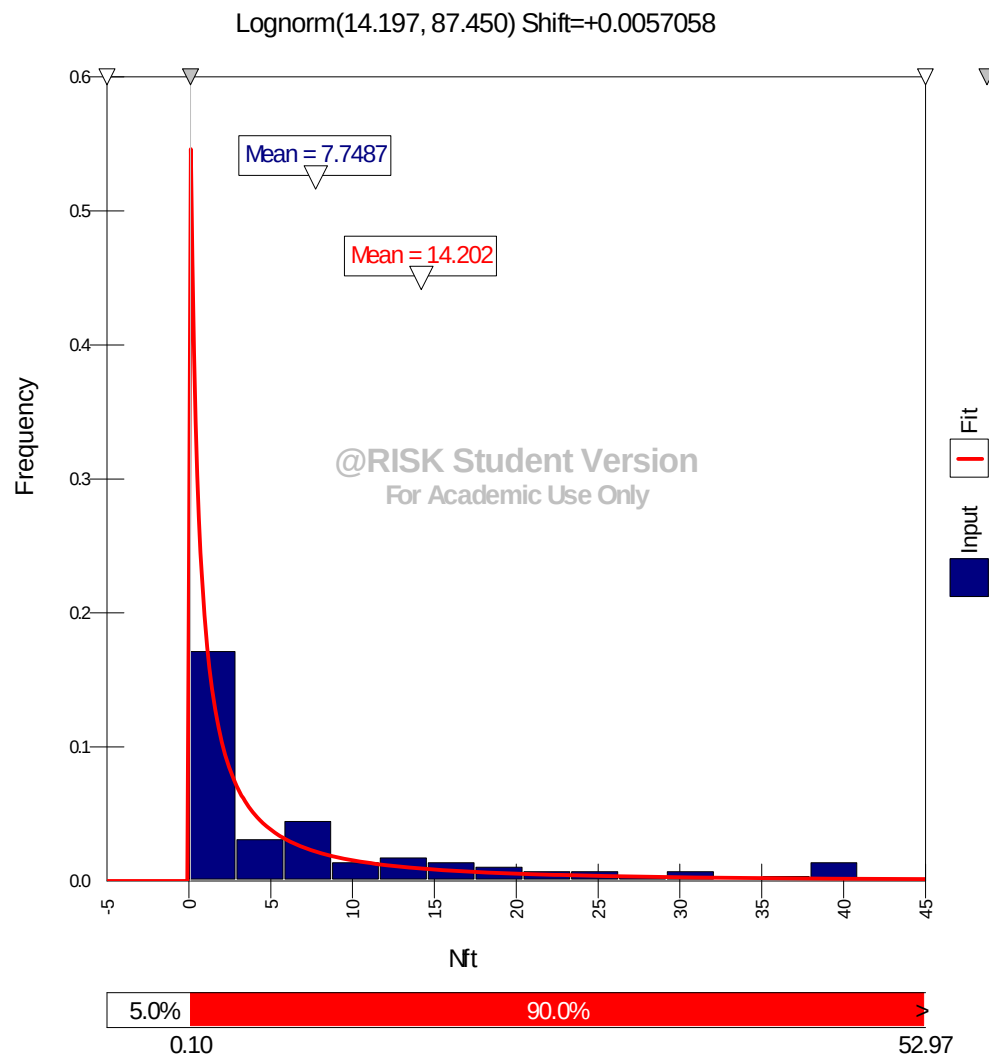


Figure D.3.15 Mechanical Based on Time

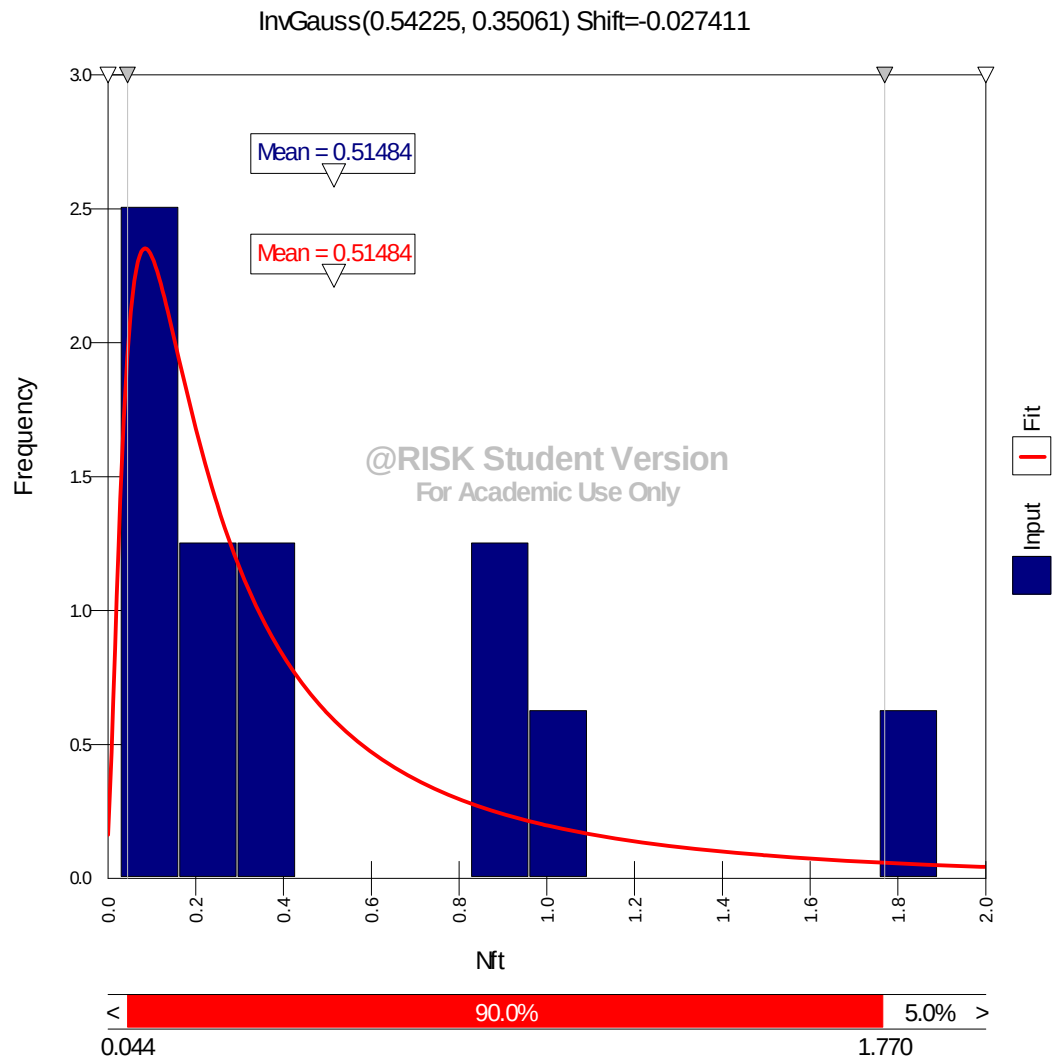


Figure D.3.16 Furnish & Install Furnish & Install Pipes & Fittings Based on Time

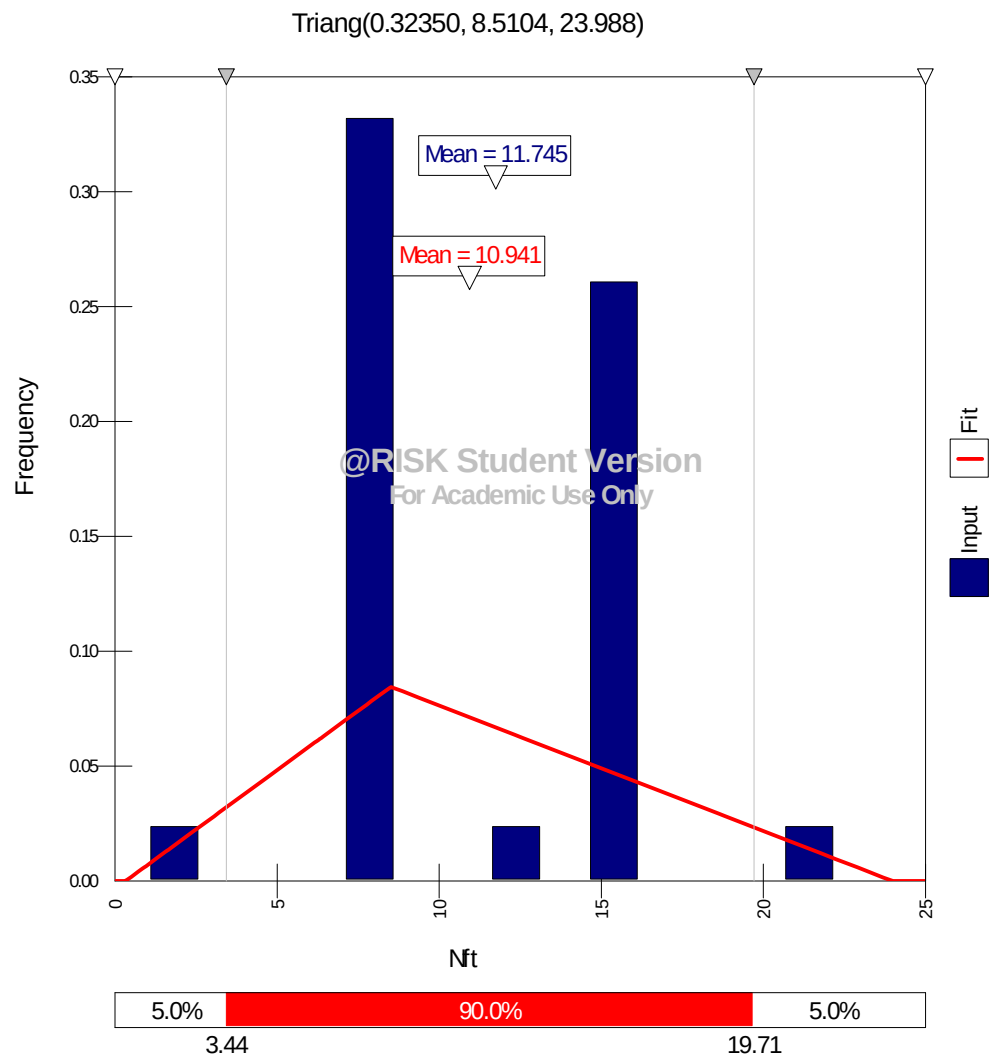


Figure D.3.17 Furnish & Install Thermal and Moist Based on Time

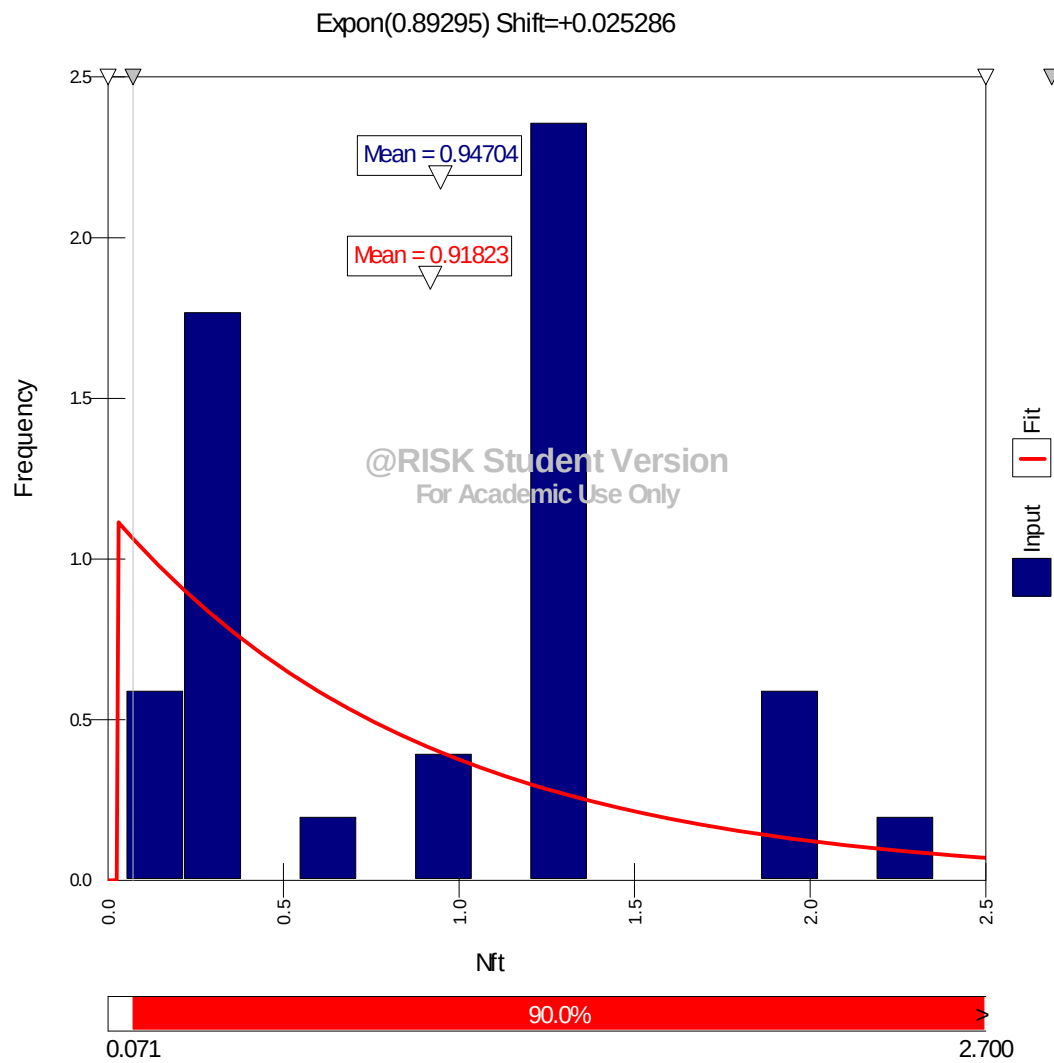


Figure D.3.18 Furnish & Install Doors and Windows Based on Time

Fit Run Based on Cost	1 st				2 nd				
Activity	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq
Furnish Concrete	1,000,000	InvGauss	7	1	90	15.2	BetaGeneral	8	0.5
Install Formwork	1,000,000	Pearson5	8	10.59	90	12.7	LogLogistic	6	6.753
Install Rebar	1,000,000	Pearson5	7	6	90	3.3	Lognorm	3	2.963
Pour Concrete	1,000,000	Lognorm	7	13.74	90	65	Pearson5	5	5.543
Finish Concrete	1,000,000	Lognorm	7	8.25	90	8.8	InvGauss	5	3.122
Furnish & Install Grout	1,000,000	InvGauss	5	0.7143	90	9.35	InvGauss	5	1.692
Excavation	1,000,000	InvGauss	5	1.784	90	9.55	Pearson5	5	4.97
Place Fills	1,000,000	InvGauss	6	7.2	90	61.9	LogLogistic	4	3.676
Change Orders	1,000,000	InvGauss	5	0.1111	90	11.1	Expon	6	0.5
Unit Prices	1,000,000	InvGauss	6	30.46	90	8.32	ExtValue	6	58.24
Cut-Off, Haul & Dispose Piles	1,000,000	InvGauss	6	12.8	90	15.8	LogLogistic	4	17
Concrete Demolition	1,000,000	Lognorm	5	10.68	90	68.93	Lognorm	5	10.68
F & I Structural Steel	1,000,000	BetaGeneral	5	1.286	90	26.23	BetaGeneral	6	0.6667
F & I Miscellaneous Metal	1,000,000	Pearson5	7	2.449	90	41.4	InvGauss	5	2.431
Mechanical	1,000,000	Pearson5	7	21.29	90	209	InvGauss	5	19.82
Furnish & Install Pipes & Fittings	1,000,000	InvGauss	4	0.5714	90	5.425	InvGauss	4	0.1538
Thermal & Moist Protection	1,000,000	Lognorm	5	18.4	90	58.7	BetaGeneral	4	19.14
Doors & Windows	1,000,000	Lognorm	4	14.94	90	1.355	Lognorm	4	14.94

Table D.4.1 Fitted Distribution Runs 1 and 2 Based on Cost

Fit Run Based on Cost	3rd					4th				
Activity	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq
Furnish Concrete	90	3.906	Expon	7	0.1429	90	0.981	Expon	8	0
Install Formwork	90	4.66	ExtValue	6	5.75	90	2.252	BetaGeneral	6	4.123
Install Rebar	90	1.578	InvGauss	3	5.846	90	1.254	Weibull	2	3.02
Pour Concrete	90	26.31	LogLogistic	4	5.846	90	20.15	LogLogistic	4	10.2
Finish Concrete	90	2.762	Lognorm	3	3.026	90	2.0069	Lognorm	3	1.895
Furnish & Install Grout	90	3.779	InvGauss	3	0.1667	90	2.433	InvGauss	3	2
Excavation	90	2.792	Expon	3	2.5	90	1.474	Logistic	3	2
Place Fills	90	26.11	InvGauss	4	4.8	90	14.79	Logistic	3	0.25
Change Orders	90	1.205	BetaGeneral	6	0.1429	90	0.7529	Expon	6	0
Unit Prices	90	1.072	Expon	2	26.67	90	0.496	Pareto	6	38.17
Cut-Off, Haul & Dispose Piles	90	4.76	InvGauss	3	14.63	90	3.328	BetaGeneral	3	8.722
Concrete Demolition										
F & I Structural Steel	90	7.892	BetaGeneral	6	0.2	90	2.519	N/A	N/A	N/A
F & I Miscellaneous Metal	90	13.24	Pearson5	5	2.885	90	8.16	Expon	4	4.105
Mechanical	90	48.4	BetaGeneral	4	15.34					
Furnish & Install Pipes & Fittings	90	3.274	InvGauss	4	0					
Thermal & Moist Protection										
Doors & Windows										

Table D.4.2 Fitted Distribution Runs 3 and 4 Based on Cost

Fit Run Based on Cost	5th					6th				
Activity	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq
Furnish Concrete	90	0.606	BetaGeneral	8	0.2	90	0.2247	N/A	N/A	N/A
Install Formwork	90	1.814	LogLogistic	5	4.478					
Install Rebar	90	0.992	Weibull	2	5.824	90	0.796	Triang	2	6.437
Pour Concrete										
Finish Concrete	90	1.798	BetaGeneral	3	1.405	90	1.261	Expon	3	2
Furnish & Install Grout	90	1.6	InvGauss	3	0	90	1.079	ExtValue	3	0.1579
Excavation	90	0.703	Expon	3	2.846	90	0.742	Expon	3	2.846
Place Fills	90	5.858	Logistic	3	1.571	90	4.285	Normal	6	0.5926
Change Orders										
Unit Prices	90	3.5813	InvGauss	5	51.44	90	1.082	Expon	2	26.67
Cut-Off, Haul & Dispose Piles	90	2.472	LogLogistic	3	16.4	90	2.931	BetaGeneral	3	8.722
Concrete Demolition										
F & I Structural Steel										
F & I Miscellaneous Metal	90	3.254	Expon	3	3.038					
Mechanical										
Furnish & Install Pipes & Fittings										
Thermal & Moist Protection										
Doors & Windows										

Table D.4.3 Fitted Distribution Runs 5 and 6 Based on Cost

Fit Run Based on Cost	7th				
Activity	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq
Furnish Concrete					
Install Formwork					
Install Rebar					
Pour Concrete					
Finish Concrete					
Furnish & Install Grout					
Excavation					
Place Fills					
Change Orders					
Unit Prices					
Cut-Off, Haul & Dispose Piles	90	2.472	LogLogistic	3	16.4
Concrete Demolition					
F & I Structural Steel					
F & I Miscellaneous Metal					
Mechanical					
Furnish & Install Pipes & Fittings					
Thermal & Moist Protection					
Doors & Windows					

Table D.4.4 Fitted Distribution Run 7 Based on Cost

Fit Run Based on Time	1st				2nd				
Activity	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq
Furnish Concrete	1,000,000	InvGauss	6	1	90	15.1	BetaGeneral	5	0.5
Install Formwork	1,000,000	Pearson5	6	14.28	90	13.9	Expon	4	10.95
Install Rebar	1,000,000	Pearson5	6	7.474	90	3.8	LogLogistic	3	4.667
Pour Concrete	1,000,000	Pearson5	6	4.341	90	55	Lognorm	5	3.911
Finish Concrete	1,000,000	Pearson5	6	3.079	90	11.82	Pearson5	5	6.193
Furnish & Install Grout	1,000,000	Lognorm	5	4.4	90	10.66	InvGauss	4	6.519
Excavation	1,000,000	InvGauss	5	1.722	90	7.92	InvGauss	5	2
Place Fills	1,000,000	Lognorm	5	14	90	67.4	Pearson5	5	11.2
Change Orders	1,000,000	InvGauss	5	2	90	34	Expon	5	0.1429
Unit Prices	1,000,000	Pareto	6	52	90	27.82	Pearson5	6	54.8
Cut-Off, Haul & Dispose Piles	1,000,000	InvGauss	6	11.6	90	21.8	Expon	4	11.67
Concrete Demolition	1,000,000	Pearson5	5	13.77	90	121.34	Pearson5	5	13.77
F & I Structural Steel	1,000,000	Expon	5	0.6667	90	16.49	ExtValue	4	0.2
F & I Miscellaneous Metal	1,000,000	Pearson5	6	3.176	90	56.5	Lognorm	5	0.5714
Mechanical	1,000,000	Lognorm	5	13.34	90	88.5	InvGauss	5	23.87
Furnish & Install Pipes & Fittings	1,000,000	InvGauss	5	0.5714	90	6.5	InvGauss	4	0.1538
Thermal & Moist Protection	1,000,000	ExtValue	3	34.8	90	32.4	Triang	5	26.43
Doors & Windows	1,000,000	InvGauss	4	16.5	90	2.996	Expon	3	18.35

Table D.5.1 Fitted Distribution Runs 1 and 2 Based on Time

Fit Run Based on Time	3rd					4th				
Activity	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq
Furnish Concrete	90	0.3214	BetaGeneral	5	0.2	90	0.1757	N/A	N/A	N/A
Install Formwork	90	4.48	Pearson5	3	5.5	90	2.736	Normal	2	4.867
Install Rebar	90	1.93	LogLogistic	3	6.302	90	1.768	InvGauss	3	4
Pour Concrete	90	24.04	Expon	4	8.973	90	12.63	Expon	3	6.706
Finish Concrete	90	4.06	Lognorm	5	2.392	90	2.37	Lognorm	3	2.61
Furnish & Install Grout	90	4.79	InvGauss	3	5.154	90	3.09	Expon	3	5.6
Excavation	90	3.442	BetaGeneral	3	0.8	90	1.641	BetaGeneral	3	0.2857
Place Fills	90	37.2	Expon	4	8.973	90	14.96	LogLogistic	4	6.353
Change Orders	95	2.216	BetaGeneral	6	0					
Unit Prices	90	3.84	InvGauss	6	51.76	90	0.991	BetaGeneral	3	26
Cut-Off, Haul & Dispose Piles	90	4.39	LogLogistic	3	15.41	90	3.466	InvGauss	3	14.56
Concrete Demolition										
F & I Structural Steel	90	6.366	N/A	N/A	N/A					
F & I Miscellaneous Metal	90	12.95	Pearson5	5	1.254	90	7.36	LogLogistic	3	2.842
Mechanical	90	43	Lognorm	4	13.74					
Furnish & Install Pipes & Fittings	90	3.428	InvGauss	4	0					
Thermal & Moist Protection										
Doors & Windows										

Table D.4.2 Fitted Distribution Runs 3 and 4 Based on Time

Fit Run Based on Time	5th					6th				
Activity	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq
Furnish Concrete										
Install Formwork										
Install Rebar	90	0.958	BetaGeneral	2	2.611	90	0.958	Weibull	2	2.09
Pour Concrete	90	9.12	Pearson5	3	3.5	90	8.659	Pearson5	3	3.5
Finish Concrete										
Furnish & Install Grout	90	2.336	InvGauss	3	3.739	90	1.937	InvGauss	3	5.095
Excavation	90	1.159	Triang	3	1.308	90	0.7935	Logistic	3	2
Place Fills	90	10.76	Pearson5	3	4.375	90	7.23	Normal	2	2.4
Change Orders										
Unit Prices	90	0.4535	Pareto	6	36.43	90	3.6029	InvGauss	6	51.76
Cut-Off, Haul & Dispose Piles	90	2.66	InvGauss	4	14					
Concrete Demolition										
F & I Structural Steel										
F & I Miscellaneous Metal	90									
Mechanical										
Furnish & Install Pipes & Fittings										
Thermal & Moist Protection										
Doors & Windows										

Table D.4.3 Fitted Distribution Runs 5 and 6 Based on Time

Fit Run Based on Time	7th				
Activity	Diff. Fit P	Right X	Fitted Distribution	# of Invalid Fits	Chi-Sq
Furnish Concrete					
Install Formwork					
Install Rebar					
Pour Concrete					
Finish Concrete					
Furnish & Install Grout					
Excavation					
Place Fills	90	5.361	Uniform	6	6.286
Change Orders					
Unit Prices					
Cut-Off, Haul & Dispose Piles					
Concrete Demolition					
F & I Structural Steel					
F & I Miscellaneous Metal					
Mechanical					
Furnish & Install Pipes & Fittings					
Thermal & Moist Protection					
Doors & Windows					

Table D.4.4 Fitted Distribution Run 7 Based on Time

APPENDIX E

Project Differences Report			
Comparing Systems Management Engineering Facility III Real-time to Systems Management Engineering Facility III Executed by admin Date Mon Mar 29 17:04:24 GMT-05:00 2010			
General Project Data			
Field Name		[Systems Management Engineering Facility III] [SMEFIIIIRT]	[Systems Management Engineering Facility III] [SMEFIII]
Finish Date		2010/09/2 05:00	2010/08/31 05:00
General Activity Data			
Total Float			
Activity Id	Activity Name	New Total Float	Old Total Float
A1330	Pour Deck 4	1904.0	1920.0
A1750	Rough Electrical 1	1640.0	1656.0
A1590	Install Interim Door Frames	1448.0	1464.0
A1560	Install Ceiling Sheetrock 2	1336.0	1352.0
A1320	Pour Deck 3	1904.0	1920.0
A1410	Install Studs 3	1640.0	1656.0
A1190	Fireproof 1	976.0	992.0
A1800	Rough HVAC 1	976.0	992.0
A1600	Hang Interim Doors	1448.0	1464.0
A1440	Drywall 2	1336.0	1352.0
A1520	Glass Glazing 2	1352.0	1368.0
A1840	Finish HVAC	976.0	992.0
A1540	Glass Glazing 4	1352.0	1368.0
A1790	Finish Electrical	1640.0	1656.0
A1580	Install Ceiling Sheetrock 4	1336.0	1352.0
A1830	Rough HVAC 4	976.0	992.0
A1550	Install Ceiling Sheetrock 1	1336.0	1352.0
A1850	Electrical Trim out	1640.0	1656.0
A1380	Concrete Encased Steel	2128.0	2144.0

A1480	Windows 2	1352.0	1368.0
A1490	Windows 3	1352.0	1368.0
A1280	SS 4	1904.0	1920.0
A1820	Rough HVAC 3	976.0	992.0
A1310	Prep Deck 4	1904.0	1920.0
A1220	Prep Deck 1	976.0	992.0
A1570	Install Ceiling Sheetrock 3	1336.0	1352.0
A1400	Install Studs 2	1640.0	1656.0
A1340	Start Exterior Masonry	976.0	992.0
A1610	Install Hand Tiles	1408.0	1424.0
A1360	Start Interior Masonry	1208.0	1224.0
A1880	Install Roofing	1904.0	1920.0
A1870	Install Elevator	1912.0	1928.0
A1510	Glass Glazing 1	1352.0	1368.0
A1640	Install Carpet 2	976.0	992.0
A1260	SS 3	1904.0	1920.0
A1650	Install Carpet 3	976.0	992.0
A1770	Rough Electrical 3	1640.0	1656.0
A1460	Drywall 4	1336.0	1352.0
A1700	Demountable Glass 4	976.0	992.0
A1530	Glass Glazing 3	1352.0	1368.0
A1370	Finish Interior Masonry	1208.0	1224.0
A1390	Install Studs 1	1640.0	1656.0
A1270	Fireproof 3	1904.0	1920.0
A1680	Demountable Glass 2	976.0	992.0
A1620	Finish Bathrooms	1408.0	1424.0
A1690	Demountable Glass 3	976.0	992.0
A1420	Install Studs 4	1640.0	1656.0
A1350	Finish Exterior Masonry	976.0	992.0
A1630	Install Carpet 1	976.0	992.0
A1810	Rough HVAC 2	976.0	992.0
A1180	SS 1	976.0	992.0
A1860	Elevator Pit Rough Out	1912.0	1928.0
A1500	Windows 4	1352.0	1368.0
A1290	Fireproof 4	1904.0	1920.0

A1000	Mobilize	976.0	992.0
A1670	Demountable Glass 1	976.0	992.0
A1170	Approve/Procure/Deliver Steel	976.0	992.0
A1300	Prep Deck 3	1904.0	1920.0
A1710	Paint	976.0	992.0
A1450	Drywall 3	1336.0	1352.0
A1470	Windows 1	1352.0	1368.0
A1430	Drywall 1	1336.0	1352.0
A1780	Rough Electrical 4	1640.0	1656.0
A1660	Install Carpet 4	976.0	992.0
A1240	Pour Deck 1	976.0	992.0
A1760	Rough Electrical 2	1640.0	1656.0

Free Float

Activity Id	Activity Name	New Free Float	Old Free Float
A1120	Exterior Grade Beam	1432.0	1416.0
A1030	Install Ramp	1632.0	1616.0
A1900	Pile Caps 3&4	1624.0	1608.0
A1740	Site Pavements/Sidewalks/Curbs	808.0	792.0
A1910	General Conditions	48.0	32.0
A1100	Pile Caps 1&2	1624.0	1608.0
A1250	Pour Deck 2	16.0	0.0

Dates

Early Finish Date

Activity Id	Activity Name	New Early Finish Date	Old Early Finish Date
A1330	Pour Deck 4	2010/02/08 05:00	2010/02/04 05:00
A1750	Rough Electrical 1	2010/02/18 05:00	2010/02/16 05:00
A1590	Install Interim Door Frames	2010/05/24 05:00	2010/05/20 05:00
A1560	Install Ceiling Sheetrock 2	2010/05/14 05:00	2010/05/12 05:00
A1320	Pour Deck 3	2010/02/08 05:00	2010/02/04 05:00
A1410	Install Studs 3	2010/02/09 05:00	2010/02/05 05:00
A1800	Rough HVAC 1	2010/04/23 05:00	2010/04/21 05:00
A1600	Hang Interim Doors	2010/06/10 05:00	2010/06/08 05:00
A1440	Drywall 2	2010/05/03 05:00	2010/04/29 05:00

A1520	Glass Glazing 2	2010/06/28 05:00	2010/06/24 05:00
A1840	Finish HVAC	2010/07/20 05:00	2010/07/16 05:00
A1540	Glass Glazing 4	2010/06/28 05:00	2010/06/24 05:00
A1790	Finish Electrical	2010/04/15 05:00	2010/04/13 05:00
A1580	Install Ceiling Sheetrock 4	2010/05/14 05:00	2010/05/12 05:00
A1830	Rough HVAC 4	2010/04/23 05:00	2010/04/21 05:00
A1550	Install Ceiling Sheetrock 1	2010/05/14 05:00	2010/05/12 05:00
A1850	Electrical Trim out	2010/05/06 05:00	2010/05/04 05:00
A1380	Concrete Encased Steel	2010/02/10 05:00	2010/02/08 05:00
A1480	Windows 2	2010/06/07 05:00	2010/06/03 05:00
A1490	Windows 3	2010/06/07 05:00	2010/06/03 05:00
A1280	SS 4	2010/01/19 05:00	2010/01/15 05:00
A1820	Rough HVAC 3	2010/04/23 05:00	2010/04/21 05:00
A1310	Prep Deck 4	2010/02/01 05:00	2010/01/28 05:00
A1220	Prep Deck 1	2009/12/18 05:00	2009/12/16 05:00
A1570	Install Ceiling Sheetrock 3	2010/05/14 05:00	2010/05/12 05:00
A1400	Install Studs 2	2010/02/09 05:00	2010/02/05 05:00
A1340	Start Exterior Masonry	2010/02/08 05:00	2010/02/04 05:00
A1610	Install Hand Tiles	2010/06/03 05:00	2010/06/01 05:00
A1360	Start Interior Masonry	2010/01/18 05:00	2010/01/14 05:00
A1880	Install Roofing	2010/03/22 05:00	2010/03/18 05:00
A1870	Install Elevator	2010/03/19 05:00	2010/03/17 05:00
A1510	Glass Glazing 1	2010/06/28 05:00	2010/06/24 05:00
A1640	Install Carpet 2	2010/08/20 05:00	2010/08/18 05:00
A1260	SS 3	2010/01/19 05:00	2010/01/15 05:00
A1650	Install Carpet 3	2010/08/20 05:00	2010/08/18 05:00
A1770	Rough Electrical 3	2010/02/18 05:00	2010/02/16 05:00
A1460	Drywall 4	2010/05/03 05:00	2010/04/29 05:00
A1700	Demountable Glass 4	2010/09/02 05:00	2010/08/31 05:00
A1530	Glass Glazing 3	2010/06/28 05:00	2010/06/24 05:00
A1370	Finish Interior Masonry	2010/02/02 05:00	2010/01/29 05:00
A1390	Install Studs 1	2010/02/09 05:00	2010/02/05 05:00
A1270	Fireproof 3	2010/01/26 05:00	2010/01/22 05:00
A1680	Demountable Glass 2	2010/09/02 05:00	2010/08/31 05:00
A1620	Finish Bathrooms	2010/06/17 05:00	2010/06/15 05:00

A1690	Demountable Glass 3	2010/09/02 05:00	2010/08/31 05:00
A1420	Install Studs 4	2010/02/09 05:00	2010/02/05 05:00
A1350	Finish Exterior Masonry	2010/03/15 05:00	2010/03/11 05:00
A1630	Install Carpet 1	2010/08/20 05:00	2010/08/18 05:00
A1810	Rough HVAC 2	2010/04/23 05:00	2010/04/21 05:00
A1860	Elevator Pit Rough Out	2010/02/05 05:00	2010/02/03 05:00
A1500	Windows 4	2010/06/07 05:00	2010/06/03 05:00
A1290	Fireproof 4	2010/01/26 05:00	2010/01/22 05:00
A1670	Demountable Glass 1	2010/09/02 05:00	2010/08/31 05:00
A1300	Prep Deck 3	2010/02/01 05:00	2010/01/28 05:00
A1710	Paint	2010/08/05 05:00	2010/08/03 05:00
A1450	Drywall 3	2010/05/03 05:00	2010/04/29 05:00
A1470	Windows 1	2010/06/07 05:00	2010/06/03 05:00
A1430	Drywall 1	2010/05/03 05:00	2010/04/29 05:00
A1780	Rough Electrical 4	2010/02/18 05:00	2010/02/16 05:00
A1660	Install Carpet 4	2010/08/20 05:00	2010/08/18 05:00
A1240	Pour Deck 1	2009/12/28 05:00	2009/12/23 05:00
A1760	Rough Electrical 2	2010/02/18 05:00	2010/02/16 05:00

Early Start Date

Activity Id	Activity Name	New Early Start Date	Old Early Start Date
A1330	Pour Deck 4	2010/02/02 08:00	2010/01/29 08:00
A1750	Rough Electrical 1	2010/02/10 08:00	2010/02/08 08:00
A1590	Install Interim Door Frames	2010/05/04 08:00	2010/04/30 08:00
A1560	Install Ceiling Sheetrock 2	2010/05/04 08:00	2010/04/30 08:00
A1320	Pour Deck 3	2010/02/02 08:00	2010/01/29 08:00
A1410	Install Studs 3	2010/02/03 08:00	2010/02/01 08:00
A1800	Rough HVAC 1	2010/03/16 08:00	2010/03/12 08:00
A1600	Hang Interim Doors	2010/05/25 08:00	2010/05/21 08:00
A1440	Drywall 2	2010/04/26 08:00	2010/04/22 08:00
A1520	Glass Glazing 2	2010/06/08 08:00	2010/06/04 08:00
A1840	Finish HVAC	2010/04/26 08:00	2010/04/22 08:00
A1540	Glass Glazing 4	2010/06/08 08:00	2010/06/04 08:00
A1790	Finish Electrical	2010/02/19 08:00	2010/02/17 08:00
A1580	Install Ceiling Sheetrock 4	2010/05/04 08:00	2010/04/30 08:00

A1830	Rough HVAC 4	2010/03/16 08:00	2010/03/12 08:00
A1550	Install Ceiling Sheetrock 1	2010/05/04 08:00	2010/04/30 08:00
A1850	Electrical Trim out	2010/04/16 08:00	2010/04/14 08:00
A1380	Concrete Encased Steel	2010/01/20 08:00	2010/01/18 08:00
A1480	Windows 2	2010/05/04 08:00	2010/04/30 08:00
A1490	Windows 3	2010/05/04 08:00	2010/04/30 08:00
A1280	SS 4	2009/12/29 08:00	2009/12/24 08:00
A1820	Rough HVAC 3	2010/03/16 08:00	2010/03/12 08:00
A1310	Prep Deck 4	2010/01/27 08:00	2010/01/25 08:00
A1570	Install Ceiling Sheetrock 3	2010/05/04 08:00	2010/04/30 08:00
A1400	Install Studs 2	2010/02/03 08:00	2010/02/01 08:00
A1340	Start Exterior Masonry	2009/12/29 08:00	2009/12/24 08:00
A1610	Install Hand Tiles	2010/05/17 08:00	2010/05/13 08:00
A1360	Start Interior Masonry	2009/12/29 08:00	2009/12/24 08:00
A1880	Install Roofing	2010/02/09 08:00	2010/02/05 08:00
A1870	Install Elevator	2010/02/08 08:00	2010/02/04 08:00
A1510	Glass Glazing 1	2010/06/08 08:00	2010/06/04 08:00
A1640	Install Carpet 2	2010/08/06 08:00	2010/08/04 08:00
A1260	SS 3	2009/12/29 08:00	2009/12/24 08:00
A1650	Install Carpet 3	2010/08/06 08:00	2010/08/04 08:00
A1770	Rough Electrical 3	2010/02/10 08:00	2010/02/08 08:00
A1460	Drywall 4	2010/04/26 08:00	2010/04/22 08:00
A1700	Demountable Glass 4	2010/08/23 08:00	2010/08/19 08:00
A1530	Glass Glazing 3	2010/06/08 08:00	2010/06/04 08:00
A1370	Finish Interior Masonry	2010/01/19 08:00	2010/01/15 08:00
A1390	Install Studs 1	2010/02/03 08:00	2010/02/01 08:00
A1270	Fireproof 3	2010/01/20 08:00	2010/01/18 08:00
A1680	Demountable Glass 2	2010/08/23 08:00	2010/08/19 08:00
A1620	Finish Bathrooms	2010/06/04 08:00	2010/06/02 08:00
A1690	Demountable Glass 3	2010/08/23 08:00	2010/08/19 08:00
A1420	Install Studs 4	2010/02/03 08:00	2010/02/01 08:00
A1350	Finish Exterior Masonry	2010/02/09 08:00	2010/02/05 08:00
A1630	Install Carpet 1	2010/08/06 08:00	2010/08/04 08:00
A1810	Rough HVAC 2	2010/03/16 08:00	2010/03/12 08:00
A1860	Elevator Pit Rough Out	2010/02/02 08:00	2010/01/29 08:00

A1500	Windows 4	2010/05/04 08:00	2010/04/30 08:00
A1290	Fireproof 4	2010/01/20 08:00	2010/01/18 08:00
A1670	Demountable Glass 1	2010/08/23 08:00	2010/08/19 08:00
A1300	Prep Deck 3	2010/01/27 08:00	2010/01/25 08:00
A1710	Paint	2010/07/21 08:00	2010/07/19 08:00
A1450	Drywall 3	2010/04/26 08:00	2010/04/22 08:00
A1470	Windows 1	2010/05/04 08:00	2010/04/30 08:00
A1430	Drywall 1	2010/04/26 08:00	2010/04/22 08:00
A1780	Rough Electrical 4	2010/02/10 08:00	2010/02/08 08:00
A1660	Install Carpet 4	2010/08/06 08:00	2010/08/04 08:00
A1240	Pour Deck 1	2009/12/21 08:00	2009/12/17 08:00
A1760	Rough Electrical 2	2010/02/10 08:00	2010/02/08 08:00

Planned Finish Date

Activity Id	Activity Name	New Planned Finish Date	Old Planned Finish Date
A1330	Pour Deck 4	2010/02/08 05:00	2010/02/04 05:00
A1750	Rough Electrical 1	2010/02/18 05:00	2010/02/16 05:00
A1590	Install Interim Door Frames	2010/05/24 05:00	2010/05/20 05:00
A1560	Install Ceiling Sheetrock 2	2010/05/14 05:00	2010/05/12 05:00
A1320	Pour Deck 3	2010/02/08 05:00	2010/02/04 05:00
A1410	Install Studs 3	2010/02/09 05:00	2010/02/05 05:00
A1800	Rough HVAC 1	2010/04/23 05:00	2010/04/21 05:00
A1600	Hang Interim Doors	2010/06/10 05:00	2010/06/08 05:00
A1440	Drywall 2	2010/05/03 05:00	2010/04/29 05:00
A1520	Glass Glazing 2	2010/06/28 05:00	2010/06/24 05:00
A1840	Finish HVAC	2010/07/20 05:00	2010/07/16 05:00
A1540	Glass Glazing 4	2010/06/28 05:00	2010/06/24 05:00
A1790	Finish Electrical	2010/04/15 05:00	2010/04/13 05:00
A1580	Install Ceiling Sheetrock 4	2010/05/14 05:00	2010/05/12 05:00
A1830	Rough HVAC 4	2010/04/23 05:00	2010/04/21 05:00
A1550	Install Ceiling Sheetrock 1	2010/05/14 05:00	2010/05/12 05:00
A1850	Electrical Trim out	2010/05/06 05:00	2010/05/04 05:00
A1380	Concrete Encased Steel	2010/02/10 05:00	2010/02/08 05:00
A1480	Windows 2	2010/06/07 05:00	2010/06/03 05:00
A1490	Windows 3	2010/06/07 05:00	2010/06/03 05:00

A1280	SS 4	2010/01/19 05:00	2010/01/15 05:00
A1820	Rough HVAC 3	2010/04/23 05:00	2010/04/21 05:00
A1310	Prep Deck 4	2010/02/01 05:00	2010/01/28 05:00
A1220	Prep Deck 1	2009/12/18 05:00	2009/12/16 05:00
A1570	Install Ceiling Sheetrock 3	2010/05/14 05:00	2010/05/12 05:00
A1400	Install Studs 2	2010/02/09 05:00	2010/02/05 05:00
A1340	Start Exterior Masonry	2010/02/08 05:00	2010/02/04 05:00
A1610	Install Hand Tiles	2010/06/03 05:00	2010/06/01 05:00
A1360	Start Interior Masonry	2010/01/18 05:00	2010/01/14 05:00
A1880	Install Roofing	2010/03/22 05:00	2010/03/18 05:00
A1870	Install Elevator	2010/03/19 05:00	2010/03/17 05:00
A1510	Glass Glazing 1	2010/06/28 05:00	2010/06/24 05:00
A1640	Install Carpet 2	2010/08/20 05:00	2010/08/18 05:00
A1260	SS 3	2010/01/19 05:00	2010/01/15 05:00
A1650	Install Carpet 3	2010/08/20 05:00	2010/08/18 05:00
A1770	Rough Electrical 3	2010/02/18 05:00	2010/02/16 05:00
A1460	Drywall 4	2010/05/03 05:00	2010/04/29 05:00
A1700	Demountable Glass 4	2010/09/02 05:00	2010/08/31 05:00
A1530	Glass Glazing 3	2010/06/28 05:00	2010/06/24 05:00
A1370	Finish Interior Masonry	2010/02/02 05:00	2010/01/29 05:00
A1390	Install Studs 1	2010/02/09 05:00	2010/02/05 05:00
A1270	Fireproof 3	2010/01/26 05:00	2010/01/22 05:00
A1680	Demountable Glass 2	2010/09/02 05:00	2010/08/31 05:00
A1620	Finish Bathrooms	2010/06/17 05:00	2010/06/15 05:00
A1690	Demountable Glass 3	2010/09/02 05:00	2010/08/31 05:00
A1420	Install Studs 4	2010/02/09 05:00	2010/02/05 05:00
A1350	Finish Exterior Masonry	2010/03/15 05:00	2010/03/11 05:00
A1630	Install Carpet 1	2010/08/20 05:00	2010/08/18 05:00
A1810	Rough HVAC 2	2010/04/23 05:00	2010/04/21 05:00
A1860	Elevator Pit Rough Out	2010/02/05 05:00	2010/02/03 05:00
A1500	Windows 4	2010/06/07 05:00	2010/06/03 05:00
A1290	Fireproof 4	2010/01/26 05:00	2010/01/22 05:00
A1670	Demountable Glass 1	2010/09/02 05:00	2010/08/31 05:00
A1300	Prep Deck 3	2010/02/01 05:00	2010/01/28 05:00
A1710	Paint	2010/08/05 05:00	2010/08/03 05:00

A1450	Drywall 3	2010/05/03 05:00	2010/04/29 05:00
A1470	Windows 1	2010/06/07 05:00	2010/06/03 05:00
A1430	Drywall 1	2010/05/03 05:00	2010/04/29 05:00
A1780	Rough Electrical 4	2010/02/18 05:00	2010/02/16 05:00
A1660	Install Carpet 4	2010/08/20 05:00	2010/08/18 05:00
A1240	Pour Deck 1	2009/12/28 05:00	2009/12/23 05:00
A1760	Rough Electrical 2	2010/02/18 05:00	2010/02/16 05:00

Planned Start Date

Activity Id	Activity Name	New Planned Start Date	Old Planned Start Date
A1330	Pour Deck 4	2010/02/02 08:00	2010/01/29 08:00
A1750	Rough Electrical 1	2010/02/10 08:00	2010/02/08 08:00
A1590	Install Interim Door Frames	2010/05/04 08:00	2010/04/30 08:00
A1560	Install Ceiling Sheetrock 2	2010/05/04 08:00	2010/04/30 08:00
A1320	Pour Deck 3	2010/02/02 08:00	2010/01/29 08:00
A1410	Install Studs 3	2010/02/03 08:00	2010/02/01 08:00
A1800	Rough HVAC 1	2010/03/16 08:00	2010/03/12 08:00
A1600	Hang Interim Doors	2010/05/25 08:00	2010/05/21 08:00
A1440	Drywall 2	2010/04/26 08:00	2010/04/22 08:00
A1520	Glass Glazing 2	2010/06/08 08:00	2010/06/04 08:00
A1840	Finish HVAC	2010/04/26 08:00	2010/04/22 08:00
A1540	Glass Glazing 4	2010/06/08 08:00	2010/06/04 08:00
A1790	Finish Electrical	2010/02/19 08:00	2010/02/17 08:00
A1580	Install Ceiling Sheetrock 4	2010/05/04 08:00	2010/04/30 08:00
A1830	Rough HVAC 4	2010/03/16 08:00	2010/03/12 08:00
A1550	Install Ceiling Sheetrock 1	2010/05/04 08:00	2010/04/30 08:00
A1850	Electrical Trim out	2010/04/16 08:00	2010/04/14 08:00
A1380	Concrete Encased Steel	2010/01/20 08:00	2010/01/18 08:00
A1480	Windows 2	2010/05/04 08:00	2010/04/30 08:00
A1490	Windows 3	2010/05/04 08:00	2010/04/30 08:00
A1280	SS 4	2009/12/29 08:00	2009/12/24 08:00
A1820	Rough HVAC 3	2010/03/16 08:00	2010/03/12 08:00
A1310	Prep Deck 4	2010/01/27 08:00	2010/01/25 08:00
A1570	Install Ceiling Sheetrock 3	2010/05/04 08:00	2010/04/30 08:00
A1400	Install Studs 2	2010/02/03 08:00	2010/02/01 08:00

A1340	Start Exterior Masonry	2009/12/29 08:00	2009/12/24 08:00
A1610	Install Hand Tiles	2010/05/17 08:00	2010/05/13 08:00
A1360	Start Interior Masonry	2009/12/29 08:00	2009/12/24 08:00
A1880	Install Roofing	2010/02/09 08:00	2010/02/05 08:00
A1870	Install Elevator	2010/02/08 08:00	2010/02/04 08:00
A1510	Glass Glazing 1	2010/06/08 08:00	2010/06/04 08:00
A1640	Install Carpet 2	2010/08/06 08:00	2010/08/04 08:00
A1260	SS 3	2009/12/29 08:00	2009/12/24 08:00
A1650	Install Carpet 3	2010/08/06 08:00	2010/08/04 08:00
A1770	Rough Electrical 3	2010/02/10 08:00	2010/02/08 08:00
A1460	Drywall 4	2010/04/26 08:00	2010/04/22 08:00
A1700	Demountable Glass 4	2010/08/23 08:00	2010/08/19 08:00
A1530	Glass Glazing 3	2010/06/08 08:00	2010/06/04 08:00
A1370	Finish Interior Masonry	2010/01/19 08:00	2010/01/15 08:00
A1390	Install Studs 1	2010/02/03 08:00	2010/02/01 08:00
A1270	Fireproof 3	2010/01/20 08:00	2010/01/18 08:00
A1680	Demountable Glass 2	2010/08/23 08:00	2010/08/19 08:00
A1620	Finish Bathrooms	2010/06/04 08:00	2010/06/02 08:00
A1690	Demountable Glass 3	2010/08/23 08:00	2010/08/19 08:00
A1420	Install Studs 4	2010/02/03 08:00	2010/02/01 08:00
A1350	Finish Exterior Masonry	2010/02/09 08:00	2010/02/05 08:00
A1630	Install Carpet 1	2010/08/06 08:00	2010/08/04 08:00
A1810	Rough HVAC 2	2010/03/16 08:00	2010/03/12 08:00
A1860	Elevator Pit Rough Out	2010/02/02 08:00	2010/01/29 08:00
A1500	Windows 4	2010/05/04 08:00	2010/04/30 08:00
A1290	Fireproof 4	2010/01/20 08:00	2010/01/18 08:00
A1670	Demountable Glass 1	2010/08/23 08:00	2010/08/19 08:00
A1300	Prep Deck 3	2010/01/27 08:00	2010/01/25 08:00
A1710	Paint	2010/07/21 08:00	2010/07/19 08:00
A1450	Drywall 3	2010/04/26 08:00	2010/04/22 08:00
A1470	Windows 1	2010/05/04 08:00	2010/04/30 08:00
A1430	Drywall 1	2010/04/26 08:00	2010/04/22 08:00
A1780	Rough Electrical 4	2010/02/10 08:00	2010/02/08 08:00
A1660	Install Carpet 4	2010/08/06 08:00	2010/08/04 08:00
A1240	Pour Deck 1	2009/12/21 08:00	2009/12/17 08:00

A1760	Rough Electrical 2	2010/02/10 08:00	2010/02/08 08:00
Late Finish Date			
Activity Id	Activity Name	New Late Finish Date	Old Late Finish Date
A1190	Fireproof 1	2010/06/03 05:00	2010/06/07 05:00
A1180	SS 1	2010/05/26 05:00	2010/05/28 05:00
A1000	Mobilize	2010/03/03 05:00	2010/03/05 05:00
A1170	Approve/Procure/Deliver Steel	2010/05/05 05:00	2010/05/07 05:00
Late Start Date			
Activity Id	Activity Name	New Late Start Date	Old Late Start Date
A1190	Fireproof 1	2010/05/27 08:00	2010/06/01 08:00
A1220	Prep Deck 1	2010/06/04 08:00	2010/06/08 08:00
A1180	SS 1	2010/05/06 08:00	2010/05/10 08:00
A1000	Mobilize	2010/02/25 08:00	2010/03/01 08:00
A1170	Approve/Procure/Deliver Steel	2010/03/04 08:00	2010/03/08 08:00
Durations			
Remaining Duration			
Activity Id	Activity Name	New Remaining Duration	Old Remaining Duration
A1220	Prep Deck 1	48.0	32.0
At Completion Duration			
Activity Id	Activity Name	New At Completion Duration	Old At Completion Duration
A1220	Prep Deck 1	48.0	32.0
Original Duration			
Activity Id	Activity Name	New Original Duration	Old Original Duration
A1220	Prep Deck 1	48.0	32.0
WBS Added/Deleted			
The following WBS have been added to the project			
WBS Code		WBS Name	
General Conditions		(New WBS)	
Plumbing		(New WBS)-1	
Civil		(New WBS)-5	

Electrical	(New WBS)-2
HVAC	(New WBS)-3
Structural	(New WBS)-4
Architectural	(New WBS)-6
WBS Added/Deleted	
The following WBS have been deleted from the project	
WBS Code	WBS Name
General Conditions	(New WBS)
HVAC	(New WBS)-3
Plumbing	(New WBS)-1
Architectural	(New WBS)-6
Electrical	(New WBS)-2
Civil	(New WBS)-5
Structural	(New WBS)-4
No changes have been reported in the following sections	
Section Detail	
Project Scheduling Options	
Project Budget Data	
Activity Constraints	
Activity Costs	
Activity Expenses	
Activity Percent Complete	
Activity Steps	
Activity Units	
Activity Code Assignments	
Added Activities	
Deleted Activities	
Added Activity Expenses	
Deleted Activity Expenses	
Added Activity Notes	
Deleted Activity Notes	
Added Activity Steps	
Deleted Activity Steps	
Added Activity Code Assignments	

Deleted Activity Code Assignments
Relationships
Added Predecessor Relationships
Deleted Predecessor Relationships
Added Successor Relationships
Deleted Successor Relationships
Resource Assignments
Added Resource Assignments
Deleted Resource Assignments
WBS

APPENDIX F

F.1 Literature Review of Existing Techniques for Construction Time-Cost Trade-Off

Analysis

F.2 Heuristic Methods

F.3 Mathematical Programming Models

F.4 Simulation

F.5 Genetic Algorithms

Appendix F.1 Literature Review of Existing Techniques for Construction Time-Cost Trade-Off Analysis

The critical path method (CPM) has been used in the construction industry for project scheduling and control since the 1960s. It provides a practical tool for planning and controlling construction projects [6]. Many new algorithms and techniques have been developed to enhance the usefulness of CPM [58]. Criteria conflicts have to be dealt with when two objectives (time compression and cost cutting) are subjects to be reached. This issue, referred to as time-cost trade-off problem (TCTP), was recognized by Fulkerson (1961) and Kelly (1961) in the early 1960s, just after CPM and PERT network approaches, and since then it has been analyzed [16, 46, and 74]. Time-cost trade-off (TCT) analysis is one of the most important issues in construction decision making (planning and control) and project accomplishment [42]. A TCT analysis is necessary to solve two classes of practical problems: to find the shortest project duration without exceeding a given budget and to minimize the total cost while meeting a specific deadline. These two problems can be incorporated into a generalized bicriterion optimization problem, which is used to obtain a complete time-cost profile over the set of feasible project durations. The profile has been named the Pareto front or efficient frontier because it consists of nondominated solutions in which one criterion cannot be improved on without deteriorating the other. Having the entire Pareto front is very important because it can help planners evaluate the pros and cons of each solution based on qualitative and experience-driven considerations. The cost of an activity can generally be expressed as a nonincreasing and bounded function of the duration [146]. Contractors usually use previous experiences to estimate the project duration and cost of a new

project. Typically, a project is broken down into activities to which resources can be assigned and durations and costs estimated. The activities are linked according to work sequences to form a network. CPM techniques are used to analyze the network to identify critical path(s) and project duration [86]. Using CPM, the overall project cost can be reduced by using less expensive resources for noncritical activities without impacting the project duration [42]. But in many cases, project should be implemented before the date calculated by CPM method [48].

The Construction Industry Institute (CII) defines two critical schedule components, schedule reduction (reduction in time without cost) and schedule compression (reduction in time with cost) [87]. For example, when project duration is compressed, the project will call for an increase in labor and more productive equipment, and require more demanding procurement and construction management, and then the cost will increase. Time and cost as two critical objectives of construction project management, are not independent but intricately related. Time-Cost Optimization (TCO) may be defined as a process to identify suitable construction activities for speeding up, and for deciding “by how much” so as to attain the best possible savings in both project schedule duration and resource allocation costs [39]. The concept of TCO seems simple in theory; however, just finding the least expensive way to shorten the schedule is extremely complex in practice. A project may involve multiple activities, each with variable time compression costs as well as multiple interdependences among activities due to different uncertainties. There are potentially multiple critical paths with numerous interrelated activities that result in a large number of compression sets to review [87]. Since there is a hidden trade-off relationship between project time and cost to complete

each activity of a project, it might be difficult to predict whether the total cost (i.e., the direct and indirect costs) would increase or decrease as a result of the schedule compression [39]. Direct costs for a particular plan are estimated by quantities and prices of materials, durations and costs of time spent by workers, and duration of use and cost of equipment to perform the selected operations. Indirect costs are added to include costs that are directly related to the project duration. Therefore, first direct costs and durations of operations for a particular set of resources and sequence of operations then indirect costs for that set of durations are estimated. The usual relationship is that the more resources assigned to an activity, the less time it will take to complete the activity, but cost is usually higher. Time-related indirect costs will decrease as project duration decreases but this may be at the expense of increased direct costs of a faster but less efficient set of resources and sequence of operations. Therefore a plan that has higher estimated direct costs may be preferred if it reduces project duration and related indirect costs such that the total project cost is decreased [114].

The trade-off between time and cost gives construction planners both challenges and opportunities to work out the best construction plan that optimizes time and cost to complete a project. Construction planners face the decisions of selecting appropriate resources, including crew sizes, equipment, methods, and technologies to perform the activities in order to shorten or lengthen the project duration. In many cases, projects are required to be completed within a certain duration. Adjustments are needed to change the resource assignments to optimize the resource allocations that yield the desired duration at a minimum cost [86]. Schedulers can perform TCT analysis to minimize the project cost or to minimize the total project duration. A complete analysis leads to a TCT curve

showing the relationship between total project duration and cost; and identification of the specific construction methods corresponding to each solution along the project TCT curve. Some activities can be performed more slowly, with less cost, without impacting the overall project duration since not all activities are critical. Difficulties arise because, for the hundreds of activities of a project, there are various options of completing these activities using different crew sizes or equipment. This creates the classic combinatorial search problem which takes several iterations to select the proper methods, equipment, and crew sizes that produce the minimum cost possible to obtain an acceptable overall project duration within the contractual time limit. Finding optimal decisions is difficult and time-consuming considering the number of permutations involved [43]. For example, a critical-path-method network with only eight activities, each with two options, will have 256 (2^8) alternatives. Exhaustive enumeration is not economically feasible even with very fast computers [86]. Decisions on TCO are usually done on a hit or miss basis with the complexity of large projects and the schedule impact of time-cost modifications [87].

TCT models can be categorized into two types: deterministic scheduling and nondeterministic scheduling based upon whether the activity duration is certain or not [48]. Traditional TCT models assume that time and cost of an option (a method or a mode to execute the activity) within an activity are deterministic [31, 58]. However, in reality they are uncertain, stochastic by nature and typically follow a certain kind of probabilistic distribution, as indicated by historical data. Some options are more risky than others and have a broad distribution. It is also hard to properly evaluate the options using deterministic methods if the overlaps between the options are significant.

Therefore, in performing schedule optimization, uncertainties should be considered when minimizing project duration or cost. This leads to the so-called stochastic TCTP. Simulation techniques are useful for analyzing such problems; however, a general strategy/algorithm is needed to guide the analysis to obtain optimal solutions. The stochastic nature of time and cost adds an additional dimension of complexity to the already hard to solve combinatorial problem [43].

Historical time-cost data and available options to complete a project can be modeled, so that construction engineers can identify best strategies to complete the project at minimum time and cost. Also, to decide the desired/optimal time and/or cost in planning and executing project activities what-if scenarios can be explored. Existing techniques for construction TCTPs in project scheduling can be categorized into three areas: heuristics, mathematical programming, and simulation. These techniques show both strengths and weaknesses in solving TCTP [43]. Heuristic methods are widely used for their simplicity and general ability to produce good results; however, they are problem dependent with varying effectiveness on different cases. In addition, despite the good solutions they provide, they select the processes to be shortened or expanded based on certain selection criteria, which do not guarantee optimal solutions. On the other hand, analytical techniques utilize mathematical models such as linear or dynamic programming are difficult to generalize, when used alone require great computational effort, and some approaches do not provide the optimal solution either. In addition, their computational difficulty explodes as the problem complexity grows, making them only suitable for small projects [40]. Neither heuristic methods nor mathematical programming models can obtain optimal solutions efficiently for large-scale networks

(several hundred activities with discrete time-cost relationships, which are common for most construction projects). "It has recently been shown that any exact solution algorithm for the discrete time-cost trade-off problem would very likely exhibit an exponential worst case complexity" [31]. Some researchers used operation research's methods to model and solve TCTPs [74, 92, and 127]. Also some Artificial Intelligence (AI) techniques were developed based on metaheuristic models such as simulated annealing, GAs and Particle Swarm [26, 42]. Although simulation techniques provide a good estimate for the optimal solutions, a guide to analyze the result of the simulation must be provided in order to find the solutions efficiently. The above-mentioned TCT models mainly focus on deterministic situations [48].

Contractors make TCT decisions every day in planning and managing their work. Automated TCT methods have been available for almost 30 years but have not been of use in construction decisions. Although TCT methods are conceptually interesting and useful in understanding practical time-cost decisions, current computer models are not applicable to construction work and are not useful for construction planning [114]. The following sections describe the strengths and weaknesses of the existing techniques for construction TCT problems.

Appendix F.2 Heuristic Methods

In resource-constrained scheduling, intensive research has been conducted under the consideration of renewable resource constraints in terms of minimizing project duration. Heuristic methods have enjoyed the majority of the research effort because they can find good solutions with far less computational effort than other methods. In general, these procedures provided rule-of-thumb guidelines for crashing activities with least costs but cannot guarantee optimality. Heuristics can be classified into two types: (1) Serial heuristics, in which processes are first prioritized and retain their values throughout the scheduling procedure; and (2) parallel heuristics, in which process priorities are updated each time a process is scheduled. Examples of heuristic approaches include Fondahl's method (1961), Prager's structural model (1963), Siemens's effective cost slope model (1971), Bell and Han (1991), Kahattab and Choobineh (1991), Boctor (1993), and Moselhi's structural stiffness method (1993) [12, 17, 45, 72, 98, 111, and 122]. There was also some approximation [125] for larger problems. Most heuristic methods assume only linear time-cost relationships within activities. In addition, the solutions obtained by heuristic methods do not provide the range of possible solutions, making it difficult to experiment with different scenarios for what-if analyses [42]. Although heuristics provide good solutions, the performance is problem-dependent, and good solutions are not guaranteed [43].

Appendix F.3 Mathematical Programming Models

Mathematical programming methods convert CPM network and TCTPs into standard mathematical programming models (constraints and objective functions) and utilize linear programming (LP), integer programming (IP), hybrid of linear and integer or dynamic programming (DP) algorithms to obtain the optimal solution. The advantages of mathematical approaches include efficiency and accuracy. However, formulating constraints and objective function is time-consuming and prone to errors. Many studies have been conducted on developing analytical techniques for solving TCTPs [9, 29, 97, 102 and 123]. Khosrowshahi (1997) contrasted the representative capacity of several mathematical models in representing the relationships between cost and duration of housing projects in Hong Kong [75].

Conventionally, the activity time-cost function in the TCT analysis was assumed to be linear [46]. Kelly (1961) formulated TCTPs using LP by assuming linear time-cost relationships within processes [74]. Other approaches, such as those by Phillips and Dessouky (1977), Hendrickson and Au (1989), and Pagnoni (1990), also use LP to solve the TCTP [64, 107, and 109]. LP approaches are suitable for problems with linear time-cost relationships but fail to solve those with discrete time-cost relationships. Generally, in fuzzy LP problems, the coefficients of decision variables are fuzzy whereas decision variables are crisp numbers. This means that, in an uncertain environment, a crisp decision is made to meet some decision criteria. Initially, Tanaka *et al.* (1984) proposed a possibilistic LP formulation where the coefficients of decision variables are crisp whereas decision variables are obtained as fuzzy numbers [128]. As an extension of this idea, Guo *et al.* (1996) have used LP and quadratic programming techniques to obtain fuzzy

solutions [53]. Tanaka *et al.* (1997) dealt with the interactive case in which exponential distribution functions are used [129]. Buckley *et al.* (2001) developed a new approach to solve multi objective LP problems in which all the parameters and variables are fuzzy numbers [19]. In the other model, Tanaka *et al.* (2000) took into consideration three kinds of possibility distribution for decision variables; interval possibility distribution, triangular possibility distribution and exponential possibility distribution [130]. Possibility distribution of fuzzy parameters and each decision variable must be symmetric in their approach, but estimations are usually asymmetric in the real world. For example, in the TCTP, estimation of normal and crash durations mostly are asymmetric. Ghazanfari *et al.* (2008) developed an optimal mathematical approach based on fuzzy distance to solve possibility goal programming. In this approach, fuzzy (uncertain) parameters and possibility distribution of decision variables are triangular that can be asymmetric [48].

Since uncertainties in the problem have received less attention due its complexity, most of the researches have been focused on deterministic problems. However, duration and cost of activities may face significant changes due to existing uncertainties such as inflation, economical and social stresses, execution errors of contractor, design errors, resource availability, natural events such as climate changes and etc. in real construction projects [39]. Therefore, uncertain models (capable of formulating vagueness in the real world) should be considered when minimizing project cost and duration, which leads to the so-called stochastic TCTP and give scheduling more stability against environmental variations [43]. On the other hand, crisp decision making in uncertain environment causes loss of some parts of information. One way to optimize TCT combinations for all

activities is to use LP. The basic assumption of linear cost-duration relationships, based on the normal and crashed points only, renders the obtained solutions only usable as approximate starting points rather than actual optima [21].

DP is the process of making a sequence of interrelated decisions. The procedure starts with a small portion of the original problem and finds the optimal solution for this smaller problem. Then it enlarges the problem finding the current optimal solution from the preceding one until the original problem is solved entirely. DP problems are either deterministic or probabilistic [1, 14, 35, 120, and 73]. Robinson (1975) developed a DP approach to solve TCTPs [115]. Elmagraby (1993), and De et al. (1995) used DP to solve TCTPs for a special class of networks that can be decomposed to pure series or parallel subnetworks [31, 38]. There are a number of characteristics to DP that limit its applicability to complicated multivariable problems. Among the most hindering factors is the number of functional constraints. Current DP techniques work with problems with one or two functional constraints. However, this feature makes DP a good candidate for coupling with solution procedures that address a problem globally, and generally reach near optimum solutions, especially in multimodal problems. In this coupling, DP is employed to search the vicinity of near optimum solutions reached by other procedures, such as GAs, and converge on the global optimum solution [40, 50, and 85].

The assumption of linearity was relaxed by allowing the activity time-cost function to be of different types: concave [41], convex [44], hybrid of concave and convex [94], quadratic [32], or discrete [125, 148]. Recently, efforts were devoted to address the possibility of having piecewise discontinuous activity time-cost functions [100, 144]. Meyer and Shaffer (1963) and Patterson and Huber (1974) solved TCTPs

including both linear and discrete relationships within the same activity by using mixed IP [108]. However, once the number of options to complete an activity becomes too large or the network becomes too complex, IP requires a prohibitive amount of computational effort. Reda and Carr (1989) applied mixed IP to solve the TCTP within related activities [114]. Liu et al. (1995) employed LP/IP hybrid mathematical method to generate a lower bound of the minimum direct cost curve efficiently through LP and the convex hull method and then find the exact solution by means of IP [86]. Burns et al. (1996) took a hybrid approach that used LP to find a lower bound of the trade-off curve; and IP to find the exact solution for any desired duration [20].

Although linear continuous cases, built with linear and DP models are widely described, their practical usability is rather limited. The more in line with practice models with discrete cost-duration functions were proposed in the late 1970s by Harvey and Patterson (1979) and Hindelang and Muth (1979) [59, 65]. These formulations make use of enumeration algorithms and DP approaches [16].

Appendix F.4 Simulation

Finding the optimal solutions for construction TCO in a stochastic network has proven to be a difficult problem to solve. For example, if the durations of the options were random variables (continuous or discrete), the evaluation process would involve excessive numerical integration, which makes it practically impossible. Although simulation techniques have been used to enhance the study of stochastic project networks, many studies focus only on estimating project duration or expenditures [33, 141]. Few studies have been conducted to optimize the project in a stochastic network. Examples are Kidd's method (1987) and Wan's perturbation analysis (1994) [76, 137]. Although they provide a good strategy to analyze the results of simulation, the above analyses do not attempt to optimize the entire project TCT curve.

Other approaches to quantify the uncertainty of durations were built by using the regular PERT technique, which assumes the beta distribution of activity durations; Monte Carlo simulation which was exploited in researches of Ang (1975), Elmaghraby (1977), and other techniques such as Goldratt's Critical Chain approach (1997) [4, 37, and 51]. The interesting approach for the TCTs in construction project was presented by Chen (2008), who used the resource matrices and elements of Earned Value method in his model, optimized in spreadsheet [25]. Recently, the latest results have been obtained in addition to the network decomposition support. Many of them were investigated by Akkan *et al.* (2005) [2].

Appendix F.5 Genetic Algorithms

GAs are search algorithms developed by Holland (1975), which are based on the mechanics of natural selection and genetics to search through decision space for optimal solutions [50, 68]. With the aid of modern AI techniques, a recent trend is to employ GAs by imitating Darwin's theory of natural selection by using random mutation, crossover, and selection procedures to generate better solutions [26, 34, 42, 62, 82, 83, 84, and 148]. In evolution, the problem each species faces is to search for beneficial adaptations to the complicated and changing environment. In GAs, a string represents a set of decisions, a potential solution to a problem. Each string is evaluated on its performance with respect to the fitness (objective) function. The ones with better performance (fitness value) are more likely to survive than the others. Then the genetic information is exchanged between strings by crossover and perturbed by mutation. The result is a new generation with (usually) better survival abilities. This process is repeated until the strings in the new generation are identical, or certain termination conditions are met. In general, conventional approaches do not need to fine-tune performance parameters (such as crossover and mutation rates) but have specific assumptions on the types of activity time-cost functions [31, 145]. In contrast, the GA is shown to be able to obtain good solutions within an acceptable time frame but requires more advanced techniques, such as niche formation [150], to maintain population diversity so as to obtain the complete Pareto front [146].

GAs have been successfully formulated to solve many science and engineering problems and have proved to be an efficient means of searching for the optimal solutions of large-scale optimization problems with great complexity [69]. In addition, GAs are

suitable for problems with multiple objectives. Successful development and application of metaheuristic optimization algorithms for solving single objective optimization problems in recent years has led researchers to investigate the possibility of their application to solve multi objective optimization problems. There exist numerous difficulties and complexities in applying metaheuristic algorithms to solve multi objective problems and several researchers have engaged in appropriate use of these methods [39]. As a result, GAs provide an alternative other than weighting for multiobjective problems. Furthermore, different versions of GAs have successfully been applied in construction scheduling optimization because there are no restrictions of using GAs in terms of uncertainties. They do not experience combinatorial explosion and they do not rely on heuristic rules, which renders them robust in tackling such problems [26, 40, 42, 62, 83, 111, and 146].

Weng-Tat and Chua (1996) presented a GA based approach for construction resource scheduling using GAs that do not depend on any set of heuristic rules, but rather on the selection and recombination operators of evolutionary algorithms to learn the domain of the specific project network [144]. Feng et. al (2000) presented a hybrid approach that combines simulation techniques and GAs to imitate the probabilistic nature of project networks throughout the search of optimal solutions and to solve the construction TCTP under uncertainty [43]. Hegazy (2001) presented a model for scheduling and cost optimization of repetitive projects with the objective to minimize total construction cost comprised of direct, indirect, interruptions, incentives, and liquidated damages cost [63]. Lue and Hwang (2001) presented a GA based searching technique to establish an optimal resource-constrained repetitive precast units' production

scheduling system with resource sharing [88]. Que (2002) introduced a hybrid approach to make GAs based on TCO tractable for real world problems via integrating a GA code with Primavera [113]. The approach utilizes activity duration-cost utility curves, and only those activities that can be crashed as defined by their utility data take part in the optimization process [40]. Zheng et al. (2004) developed a GA model for TCO problem [148]. They proposed adaptive weight approach (AWA) and modified AWA (MAWA) for solving TCO problem. Zheng and Ng (2005) extended their previous work with presenting time and cost variables in the form of fuzzy numbers to take into account the uncertainties in pre-estimates of these variables [149]. Yang (2007) developed Elitist Particle Swarm Optimization algorithm to find the complete time-cost profile (Pareto front) over a set of feasible project durations treating all existing types of activity time-cost functions, such as linear, nonlinear, discrete, discontinuous, and a hybrid of the above by adopting an elite archiving scheme to store non-dominated solutions and by aptly using members of the archive to direct further search [146]. Xiong and Kuang (2008) solved the TCO problem by combining ant colony optimization technique and AWA [143]. Ezeldin and Soliman (2009) proposed a hybrid technique that combines GAs with DP to solve construction projects TCTPs under uncertainty [40].

Uncertain scheduling models are categorized into probabilistic models and fuzzy models. One of the probabilistic models is Ang's model [4]. In many projects, the required information for estimation of project parameters is not available or is incomplete. Also in many cases the project is done for the first time, this compels us to use expert opinion in forecasting the project parameters. Some authors have claimed that fuzzy set theory is more appropriate to model these problems. Guang *et al.* (2005) offered

a new solution approach for fuzzy TCT model based on GA [24]. Leu *et al.* (2001) proposed a new fuzzy optimal TCT method and a GA-based approach to solving it [81]. Eshtehardian et al. (2008) employed GA as an optimizer where uncertainties in time, total direct and indirect cost of a construction project are considered through fuzzy logic representation to obtain appropriate solutions [39]. Arican and Gungor (2001) presented a fuzzy goal programming model for TCTP [8]. Also Chanas and Kamburowski (1981), Wan (1993), Hapk and Slowinski (1996), and Leu *et al.* (1999) developed other methods to deal with fuzzy TCTP [23, 34, 57, 80, and 138].

Planning and time scheduling of projects require three categories of analysis of time-cost trade off, leveling, and allocation of resource. Although developed techniques for TCO and resource leveling and allocation deal with two distinct subproblems, in real-world construction projects the decision makers need to consider all these aspects simultaneously. Less attention has been given to resource leveling and allocation compared with TCO. Resource allocation attempts to reschedule the project tasks so that a limited number of resources can be efficiently used while keeping the unavoidable extension of the project to a minimum. Resource leveling, on the other hand, attempts to reduce the sharp variations among the peaks and valleys in the resource demand histogram while maintaining the original project duration [96]. These techniques, as such, deal with two distinct subproblems and do not guarantee a project schedule that minimizes project time or cost [62]. Hegazy (1999a) used GA for resource leveling and allocation for the first time [61]. His work was the first attempt in finding a suboptimal solution when simultaneously solving resource allocation and leveling problems. He proposed four different equations for resource moment calculation. Hiyassat (2001)

introduced the minimum moment method for leveling of resources [66]. Son and Mattila (2004) presented a linear program binary variable model to level resources that permits selected activities to stop and restart (splitting of activities) [126]. Senouci and Eldin (2004) presented an augmented Lagrangian GA model for resource scheduling [121]. Their model incorporated precedence relationships and resource leveling and resource constrained scheduling were performed simultaneously [147]. Zahraie and Tavakolan (2009) presented a multiobjective model that simultaneously solves the TCO and resource leveling problem using non-dominated sorting GA and discrete fuzzy sets to increase the flexibility for decision makers when using the model outputs [43, 146].

In general, GA based systems for solving TCTPs suffer from two limitations. First, these systems require the user to manually craft the time-cost curves for formulating the objective functions. Second, these systems only deal with linear time-cost relationships. To overcome these limitations, Li et al. (1999) established a quadratic nonlinear model to characterize the nonlinear time-cost relations and show how the nonlinear time-cost relationships can be automatically generated from past time-cost data using a computer system called MLGAS (Machine Learning and Genetic Algorithms based System), which integrates a machine learning method with GA [84].

APPENDIX G

G.1 SMEF III Construction Estimates for 545, 455 and 365 Calendar Day Schedules

G.2 Regression Analysis on Engineer's SMEF III Construction Estimate (Nov 09)

G.2.1 Input Values

G.2.2 Summary Output

G.2.3 Normal Probability Plot

G.2.4 Days Line Fit Plot

G.2.5 Days Residual Plot

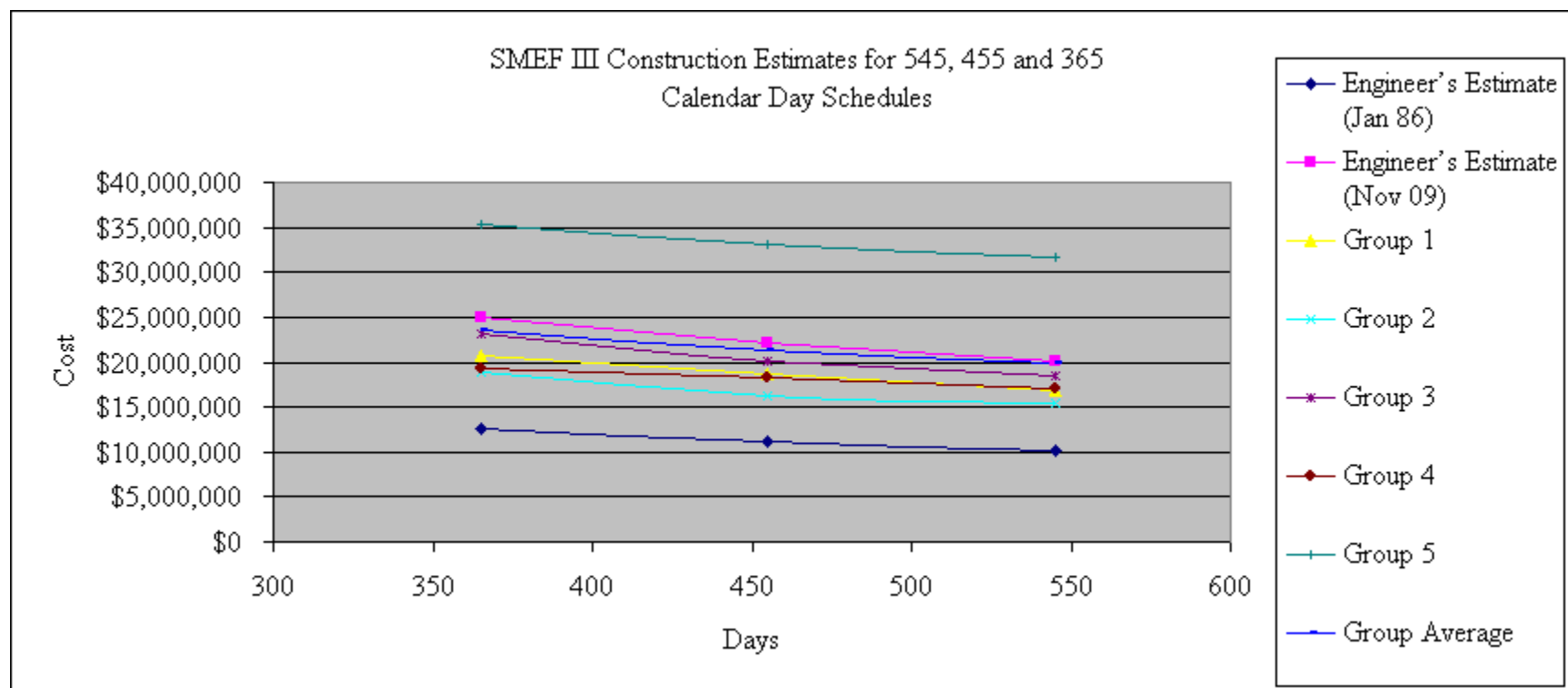


Figure G.1 SMEF III Construction Estimates for 545, 455 and 365 Calendar Day Schedules

Days	Total Cost
365	\$30,308,576
455	\$28,895,237
545	\$28,291,161

Table G.2.1 Regression Analysis Input Values from Table 5.4.2

SUMMARY OUTPUT

<i>Regression Statistics</i>	
Multiple R	0.974214106
R Square	0.949093124
Adjusted R Square	0.898186247
Standard Error	330380.2363
Observations	3

ANOVA

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	2.03498E+12	2.03498E+12	18.64371162	0.144885154
Residual	1	1.09151E+11	1.09151E+11		
Total	2	2.14413E+12			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	34264568.14	1196353.062	28.64084961	0.022218659	19063461.19	49465675.08	19063461.19	49465675.08
Days	-11207.86111	2595.712283	-4.317836451	0.144885154	-44189.51281	21773.79058	-44189.51281	21773.79058

RESIDUAL OUTPUT

	<i>Predicted</i>		<i>Standard</i>
<i>Observation</i>	<i>Total Cost</i>	<i>Residuals</i>	<i>Residuals</i>
1	30173698.83	134877.1667	0.577350269
2	29164991.33	-269754.3333	-1.154700538
3	28156283.83	134877.1667	0.577350269

PROBABILITY OUTPUT

<i>Percentile</i>	<i>Total Cost</i>
16.66666667	28291161
50	28895237
83.33333333	30308576

Table G.2.2 Regression Analysis Summary Output

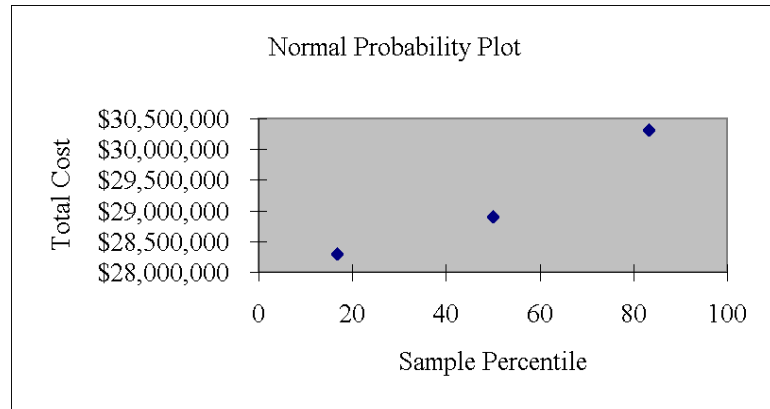


Figure G.2.3 Regression Analysis Normal Probability Plot

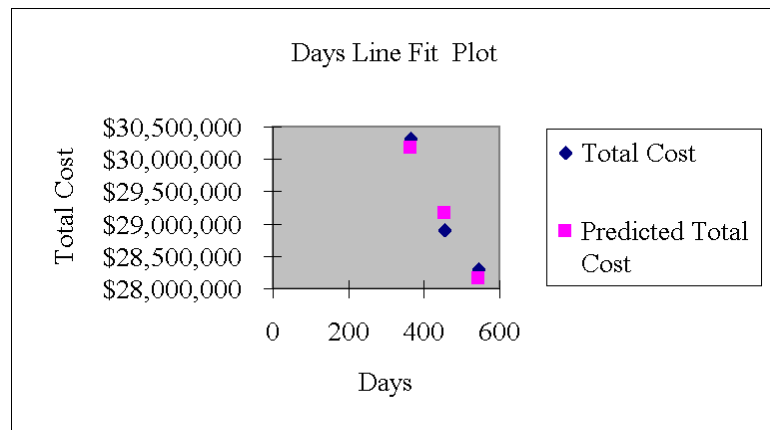


Figure G.2.4 Regression Analysis Days Line Fit Plot

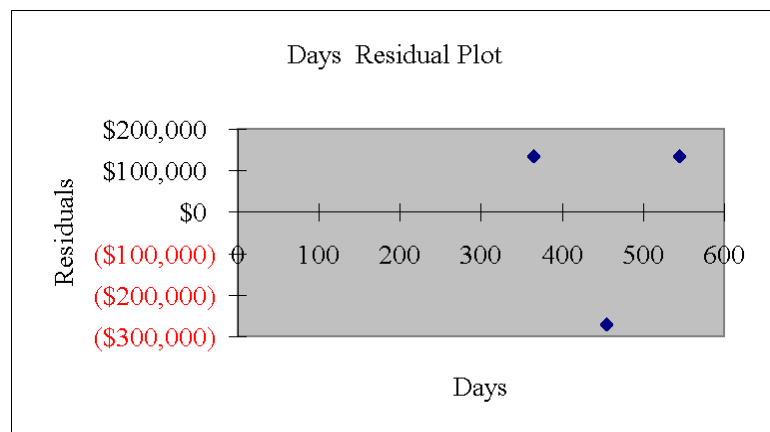


Figure G.2.5 Regression Analysis Days Residual Plot