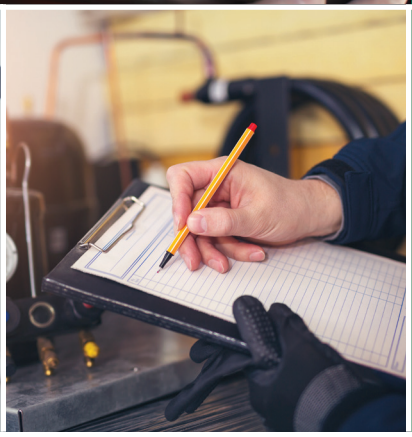
FACTORS AFFECTING LABOR PRODUCTIVITY FOR ELECTRICAL CONTRACTORS

A FACTOR APPROACH TO PRODUCTIVITY IMPACT



ELECTRI INTERNATIONAL
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Dr. Hanna is arguably North America's leading researcher working in the area of construction craft productivity. He has been active in industry-funded productivity research for nearly 20 years, with renowned research sponsors such as ELECTRI International, the Mechanical Contracting Foundation, the New Horizons Foundation, and the Construction Industry Institute, among others.

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PART 1: FACTORS AFFECTING LABOR PRODUCTIVITY FOR ELECTRICAL CONTRACTORS

INTRODUCTION AND BACKGROUND

When contractors prepare their cost estimates in today's competitive construction bidding market, they typically plan for historically achievable production rates (productivity) under ideal labor and job working conditions. However, contractors often encounter unfavorable work conditions that can result in lower-than-estimated productivity. When achieved productivity is lower than the estimate, contractors can suffer significant financial losses. Because many of these financial losses can be caused by outside interference in the contractor's performance or by events beyond their control, the contractor may be entitled to recover these losses. Lower productivity than estimated is always referred to as Loss of Productivity (LOP).

Most construction contracts contain change conditions clauses and mechanisms for equitable adjustment to the contract price and duration, as well as compensation for contractors should they experience adverse conditions beyond their control. Change Conditions can include changing the sequence of work, quantities, acceleration or compression, and site conditions. Despite this contract language, owners and contractors do not always agree on the adjusted contract price or the time it will take to incorporate the change.

Both owners and the North American legal system recognize that contractors have the right to the adjustment of contract prices for Change Conditions, including the cost associated with materials, equipment, profit, increased overhead due to changing conditions and its impact especially on labor productivity. What is needed is a logical and fair approach supported by research and data collection to estimate factors affecting labor productivity.

For ease of use, the author has compiled a list of references, attached as Appendix 2. To preserve readability of this document, the references are not incorporated into this report's individual sections. In addition, all statistical analysis, graphs, and scatterplots are provided in Appendix 3 for reference.

REVIEW OF EXISTING INDUSTRY STUDIES

There are a fair number of industry studies on the loss of productivity, such as those published by Mechanical Contractors Association of America (MCAA), U.S. Army Corps of Engineers and the Business Round Table for Scheduled Overtime. The problem with many of these studies is that they lack quantitative data, having been developed using solely subjective opinion without presenting any statistical analysis to support the subjectivity of the respondent. An additional shortcoming of published studies is a lack of quantitative definitions of common productivity factors such as stacking of trades, overmanning, and morale and attitude. In addition, the MCAA study was originally published in the 1960s, and the new editions that have been issued have not changed the factors studied nor provided sufficient explanation of how to use the factors they discovered.

Because productivity is not typically tracked by contractors, Loss of Productivity is one of the most difficult and contentious areas to prepare in a construction claim. There are several methods for quantifying LOP currently accepted by North American courts, administrative boards, and construction professionals. These include the Measured Mile Method (MMM) and the Factor Approach - the application of Productivity Loss for various unfavorable work conditions, such as overmanning, stacking of trades, beneficial occupancy and extended work hours.

This report defines **18 productivity factors** and associates a level of productivity loss with each factor. The advantage of these factors is that they were developed by qualitatively analyzing 145 projects executed in North America during the last ten years. Therefore, they are timely and pertinent to present-day construction endeavors in a way that the MMM is not. This approach can be used retroactively in cases of claiming extra cost and construction claims while projects are underway. Contractors can use this approach proactively for Forward Pricing as it allows the anticipation of these adverse conditions. This report can further be used during the estimating stage to account for known conditions preemptively.

OBJECTIVES

The purpose of this document is to develop for the electrical construction industry a standard for calculating Loss of Productivity called "Factors Affecting Labor Productivity." The new Productivity Factors are based upon a substantial data collection from 145 projects completed in both the US and Canada. Projects included in the database range from 2,000 to 260,000 work hours, **with an average of 47,380 work hours.** Percent change ranges from 10.76% to 90%. A wide range of project types were included in the database, including industrial, commercial, and institutional projects; 75% were performed for public entities; 25% for private entities. For each identified factor, this author has derived from statistical analysis three thresholds of productivity loss: minor impact, moderate impact or severe impact.

DEFINITIONS

Key definitions are found in this section. A complete glossary of terms is found in Appendix 1.

PRODUCTIVITY

Productivity is defined as the ratio between input and output. In other words, productivity is the relationship between the amount or unit of work completed and the resources put into that particular type of work or project. In construction, labor productivity can be measured as the ratio between man-hours (input) resulting in a certain amount of output, or the ratio between production units (output) and time (input).

$$\text{PRODUCTIVITY} = \frac{\text{INPUT}}{\text{OUTPUT}} \text{ OR } \frac{\text{OUTPUT}}{\text{INPUT}}$$

For example, a crew may lay 100 feet of conduit in an 8-hour shift. The productivity of that crew is .08 man-hours per foot of conduit.

$$\text{PRODUCTIVITY} = \frac{8\ \textit{HOURS}}{100\ \textit{FEET}} = .08 \text{ manhours per foot of conduit}$$

Input can also be measured in terms of costs spent to complete the work. Costs include labor, materials, equipment and other expenses. Construction productivity should always be measured in man-hours (or work-hours) rather than total costs. Man-hours and work-hours will be used interchangeably in this document. Man-hours were chosen as the primary measurement of work for this research to best account for the variable hourly rates and costs of materials across state and county lines.

LOSS OF PRODUCTIVITY

Loss of productivity occurs when a contractor experiences lower output per hour than estimated or planned. The terms Loss of Productivity (LOP) and inefficiency are used interchangeably in this document. Loss of Productivity is calculated as a percentage of the actual total hours worked per area or per project (including change order hours).

PERCENT CHANGE

The term percent change (%Change) is defined as the total owner-approved change order hours plus the total approved credit change order hours divided by the original budgeted man-hours. %Change can be calculated with the following equation:

$$\%\ \text{CHANGE} = \frac{(\text{Total Owner Approved CO Hours}) + (|\text{Total Approved Credit CO Hours}|)}{\text{Original Budgeted Man-hours}} * 100$$

REPORT OUTLINE

In this report, 18 different Productivity Factors and their corresponding loss of productivity impacts are demonstrated in Table 2.1. The impacts of each factor are delineated into three thresholds: minor, moderate, and severe impact. Following the presentation of Productivity Factors, this report provides examples on how and when they can be used (proactively or retroactively). To support the conclusion of Table 2.1, each factor is explained with its corresponding box plot in Section 3.

FACTORS AFFECTING LABOR PRODUCTIVITY

Table 2.1 below and on the following page contains a series of 18 productivity factors that evaluate Loss of Productivity (LOP) for conditions beyond the contractor's control. The table contains four columns. Column 1 lists the factors and the definition used during the course of this research. Columns 2-4 represent the percent Loss of Productivity presented as *minor, moderate,* and *severe.*

This table is deliberately modeled after other construction industry documents for ease of use. However, the basis of the categories of severity (minor, moderate, and severe) in this report is statistical analysis and quantitative data, rather than subjective opinion. The definition of severity is based on the statistical distribution of data in the box-plot format. Simply, the productivity loss values are based on the median values of the boxplot associated with the subject severity level. An asterisk in ***Table 2.1*** (*) indicates that a figure is the average of minor and severe impact.

It is crucial to note that the first factor in the below table, Cumulative Impact, results from multiple changes and should only be used at or near the conclusion of a project, once the total percentage change is known. The other 17 factors can be used retroactively or proactively as the project progresses. Furthermore, while the other 17 factors are applicable at the activity level, Cumulative Impact is only assessable at the project level.

Table 2.1: Loss of Productivity Factors

PRODUCTIVITY FACTOR (1)		MINOR (2)	MODERATE (3)	SEVERE (4)
CUMULATIVE IMPACT	Cumulative Impact is the cost associated with impact on distant work, which are not as readily foreseeable or, if foreseeable, not as readily computable as direct impact costs. The source of such costs is the sheer number and scope of changes to the contract. The result is an unanticipated loss of efficiency and productivity, which increases the contractor's performance costs and usually extends his or her stay on the job.	**Minor Cumulative Impact:** The (actual peak ÷ planned average manpower) is more than 1.6 and less than 3, and/or the average processing time is less than 7 days	**Moderate Cumulative Impact:** The (actual peak ÷ planned average manpower) is more than 3 and less than or equal to 4, and/or the average processing time is between 8 and 28 days	**Severe Cumulative Impact:** The (actual peak ÷ planned average manpower) is more than 4, and/or the average processing time is more than 28 days.
	Cumulative Impact when Percent Change is from 10% to 20%	16%	25%	35%
	Cumulative Impact when Percent Change is between 20% and 50%	21%	29%	39%
	Cumulative Impact when Percent Change is greater than 50%	27%	35%	45%
Overmanning: An increase of the peak number of workers of the same trait above the planned or estimated peak. Estimated peak typically equal to 1.6 the average number of workers.		15%	19%	33%
Overtime: The work that exceeds 8 hours/day and 40 hours/week.				
Overtime 5-10 (10 hrs/day, 5 days/week)		4%	20%	30%
Overtime 6-10 (10 hrs/day, 6 days/week)		5%	20%	40%
Second Shift: The hours worked by a second group of craftsmen whose work is performed after the first work force of the same trade has retired for the day.		-5% (gain)	10%	17%
Stacking of Trades: Considers the total number of craftsmen from all trades working in a given area. The worker density (sq. ft./worker) depends on the available net working area and the number of workers from all crafts. The net working area is the total floor space minus any unusable portions, such as a production line, elevator shaft, and permanent fixtures.		24% Density level between 200 and 300 sq. ft. per worker	28%* Density level between 100 and 200 sq. ft. per worker.	32% Density level less than 100 sq. ft. per worker

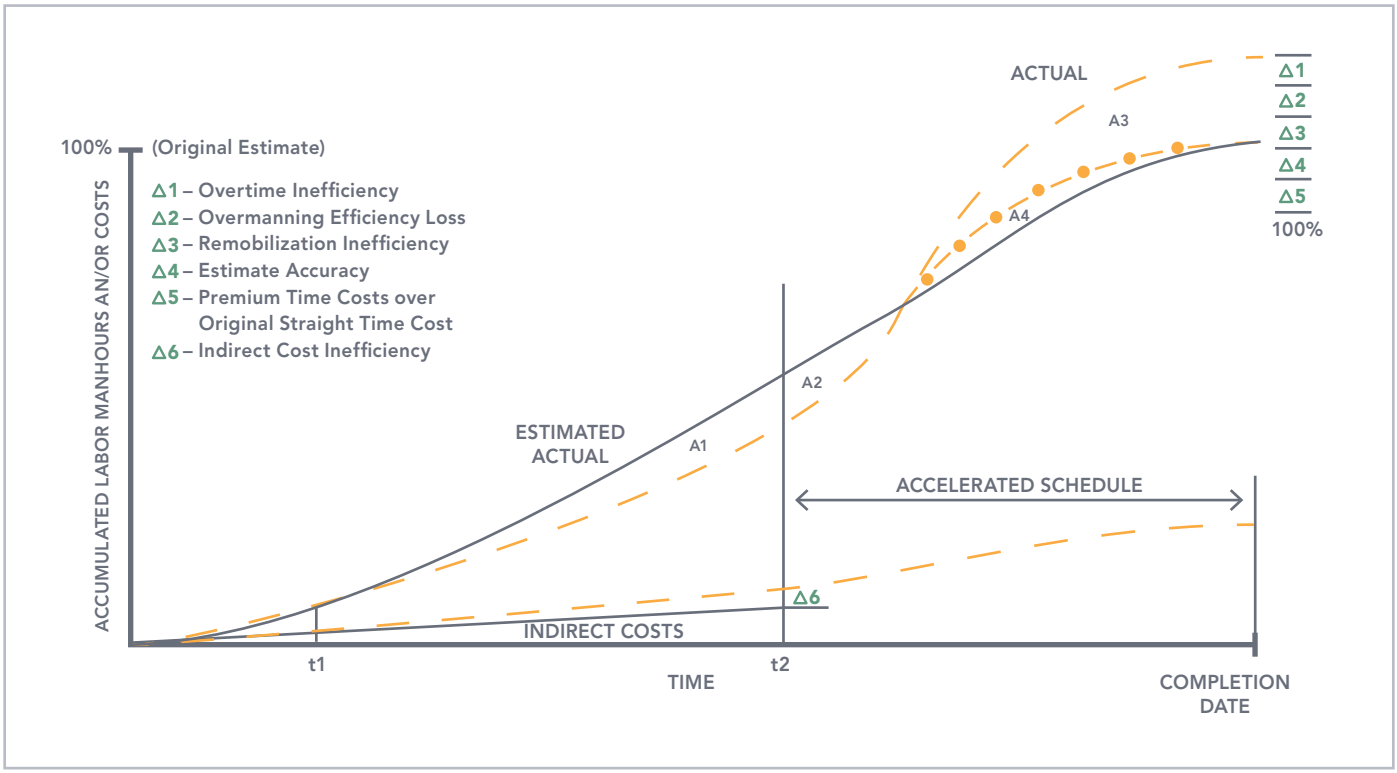
PRODUCTIVITY FACTOR (1)		MINOR (2)	MODERATE (3)	SEVERE (4)
Out-of-Sequence Work: An activity or a series of activities that is not performed according to baseline logical and productive planned sequence.		13%	22%*	31%
Weather: Impact of temperature and humidity on labor output.		0%(40 ˚F, 80˚F)	20% (0 ˚F, 100 ˚F)	40% (-10 ˚F ,110˚F)
Owner-Furnished Items: Includes both material and equipment that are bought and supplied to the specialty contractor by the owner (any part providing materials or equipment) or possibly the general contractor. See Figure 3.14 for further details.		4.3%	11.1%*	17.9%
Access Constraints: Access constraints are experienced when the work area is unavailable, partially available, or not in a condition to be used by workers.		17%	25%	32%
Beneficial Occupancy: The situation in which a contractor must work in close proximity to an owner's production equipment or personnel.		12%	20%	28%
Loss of Learning: Loss of Learning is encountered when highly repetitive operations are interrupted or personnel are changed, with the new personnel slowly learning the operations.		21%	29%	32%
Change Order Processing Time: The period of time between initiation of the change order and the owner's approval of the change order for the majority of change items experienced on the project.		0% (1-7 days)	10% (8-28 days)	15% (More than 28 days)
MORALE	**Absenteeism:** The ratio between the number of craftsmen who fail to appear for work and the number of craftsmen employed on a given project.	2% (5% absent.)	22% (10% absent.)	40% (20% absent.)
	Turnover: The ratio of the number of craftsmen hired to replace those who have left to the number of craftsmen employed on the project	4% (5% turnover)	10% (10% turnover)	20% (20% turnover)
Dilution of Supervision: This occurs when supervisors are diverted from productive work as a result of high crew levels and change order work.		25%	28%*	31%
Percent Design Complete Prior to Construction: Percentage of the design complete prior to construction.		1%(98% design)	10% (80% design)	18% (60% design)
AE Coordination Prior to Construction: Coordination with the architect/engineer prior to construction.		2%	8%*	14%
AE Support During Construction: Support provided by the architect/engineer during construction.		1%	10%	20%
Manpower Shortage During Construction		2%	8%*	14%

COMBINED EFFECTS OF PRODUCTIVITY FACTORS

The concept of individual productivity factors acting cumulatively to account for the total lost efficiency on a project was a theory first devised by Waldron in 1968. Waldron noted, from observed project situations, that at some point in time, it is decided by the contractor to accelerate the schedule to attain some fixed milestones or end date of the contract *(Waldron, 1968)*. ***Figure 2.1*** is similar to the actual sketch prepared by Waldron in 1968 to demonstrate this concept *(paraphrased as follows)*:

> *The contractor's decision to accelerate work is a result of schedule slippage that occurs from time one (t1) until time two (t2). Area A1 is the difference between the estimated production and actual production before acceleration (t2). The difference may be the result of delays, changes, or additions to the scope, and other impediments to productivity factors. At time two, additional resources and premium time are authorized, or enforced, to compensate for the lost time. As a theoretical ideal, the work hours should level out at the originally estimated 100 percent work hours. If the ordinate of Figure 2.1 was considered work hours, the area A4 under the dotted extension of the "Actual Work Hours" curve would equal the sum of areas A1 and A2. This however is not the outcome. The actual labor hours curve does not follow the balanced curve but instead is considerably higher, represented by Area A3 on Figure 2.1. The additional work hours are a result of inefficiencies that are inherent to an accelerated schedule. Furthermore, if the ordinate is taken as costs, overtime comes at a premium wage, typically time and half or double time, which also serves to increase costs.*

Figure 2.1: Waldron's Factor Approach



For successful application and utilization of Productivity Factors, the following should be considered:

- **1.** *The use of productivity factors should be accompanied by corroborating evidence. For example, when the factor is overtime, contractors should present time cards to show that workers did indeed work overtime on a particular schedule, e.g., 50 hours per week, and that overtime was needed to accelerate the schedule.*
- **2.** *Electrical estimating should be checked for accuracy and eliminated as a possible source of loss of efficiency. Usually, electrical estimating is considered accurate if the estimates of the lowest bidder and the next-lowest bidder differ by less than 10%-15% percent. If a project experiences substantial change orders, the original estimate may become outdated to the point at which it is no longer a factor in Loss of Productivity. However, the definition of substantial changes differs from organization to organization. For example, for electrical work performed for highway departments, more that 25% change is considered substantial and allows contractors to change their bidding unit rate accordingly.*
- **3.** *Contractors should always endeavor to comply with Notice Requirements pursuant to the original contract. Many modern contracts require these notices to be filed within a 48-hour window of the change in conditions.*
- **4.** *The factors defined herein are intended to be used in the case of unforeseen, inevitable conditions, rather than conditions that are present or foreseen during bidding. In the latter case, a contractor should adjust the estimate accordingly at the time of bidding.*
- **5.** *Furthermore, the factors defined here are intended to apply to situations that are beyond rectification. For example, if the owner contractually committed to purchase all fixtures for installation and those fixtures were delivered late to the point that construction was delayed through the winter months, that factor represents a situation that cannot be rectified.*
- **6.** *Contractors should seek every possible proactive solution to minimize impact. This may come in forms that result in some impact, or even uncommon working practices. For example, it is less impactful to work a second shift than it is to attempt to work under beneficial occupancy.*
- **7.** *In the case of stacking of trades or similar delays among subcontractors, the true cause of the condition is not the subcontractor but rather the owner or owner representative. In that case, a claim should be made against the owner/owner representative, as the electrical contractors and subcontractors of other trades have no contractually mandated relationship.*

HOW TO USE PRODUCTIVITY FACTORS

The following steps demonstrate how Productivity Factors can be used in hypothetical situations for a specified timeframe. This proactive use would occur at the end of each selected timeframe, rather than retroactively at the end of the completed job.

1. ***Identify a timeframe that will be analyzed. Typically, a timeframe can be selected as the interval of the pay period (one or two weeks or months).***
2. ***Break down the impacted area by location (first floor, second floor, etc.) and/or by cost code.***
3. ***Document productivity impediments, using either the foreman's daily report or any similar onsite mechanism.***

4. ***Set up a spreadsheet that reports total planned hours, defined as the planned hours for area or activity plus (estimated) change order hours.***
5. ***Apply the correct Productivity Factor and the corresponding level of severity to the impacted conditions as listed in Table 2.1 above. The exception is the Cumulative Impact factor, which, as stated in the introduction to this table, is not applicable at the activity level.***
6. ***Report total hours lost per the timeframe selected.***

The productivity factors listed in *Table 2.1* can be used either proactively or retroactively. In a case of proactive pricing where the impact is anticipated, the factors (as percentages) should be added together and multiplied by the base (or planned) work hours to determine unproductive work hours. *Table 2.2* is an example of proactive calculations of productivity loss over a five-week timeframe of a hypothetical project.

Table 2.2: Example of Proactive Calculation of Productivity Loss

	WEEKS	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14
PRODUCTIVITY FACTOR (RESEARCH)	Planned Work Hours	1400	1700	2200	1800	2800
	Change Order Hours		-100	0	200	0
	Revised Hours	1400	1600	2200	2000	2800
	Overmanning	22% (minor)	0	0	22% (minor)	0
	Stacking	28% (moderate)	0	24% (minor)	0	0
	Overtime	5% (minor)	5% (minor)	0	0	5% (minor)
	Total Factors	55%	5%	24%	22%	5%
	Estimated Loss of Productivity	770	80	528	440	140
	Total	**1958**				

APPLYING RETROACTIVE PRICING USING PRODUCTIVITY TABLES

Productivity factors can also be used retroactively against actual hours reported. In this case, the inefficient hours are already included in the actual hours reported. Therefore, the productivity factor percentages should not be multiplied by the actual hours. More appropriately, actual hours should be subtracted from the figure of actual hours divided by 1 + the pertinent factor(s), as shown below:

$$\text{ACTUAL HOURS} - \left[\frac{\text{ACTUAL HOURS}}{1+ \text{FACTORS}}\right]$$

For example, in Week 10 above (Table 2.2), proactive pricing would be calculated as follows:

$$1400 - \left[\frac{1400}{1+ 0.55}\right] = 496.7 \text{ work hours}$$

Thus, the inefficient hours amount to 496.77, and the efficient hours would be 903.23.

POSTMORTEM AND FORWARD PRICING

The following example demonstrates how Productivity Factors can be used for forward pricing.

In early April 2017, Badger Electric experienced a substantial delay as the result of late start, delay by other sub-trades, and added scope. Badger believed that, in order to complete the project on time, the company had to use overtime schedules based on 5-10 for the majority of the workforce, as the alternative would be using overmanning which has a far more severe impact on productivity. Badger decided to use Productivity Factors to implement Forward Pricing for the cost of the remaining 20 weeks of the contract, starting with the week ending on June 24. Badger is paying its electrician $40/hour straight time and $60/hour overtime. The productivity overtime factors across the 20-week overtime period can be estimated as shown ***table 2.3***.

Table 2.3: Forward Pricing Example Figures

WEEK ENDING	WEEK #...	EXPECTED AVERAGE (HOURS/WEEK)	PRODUCTIVITY OVERTIME FACTOR*	OVERTIME HOURS	TOTAL ACTUAL HOURS (INCL. OT)	LOST HOURS
4/7/2017	1	49	+10% (gain)	429	2145	-214.5
4/14/2017	2	53	-5%	598	2992	149.6
4/21/2017	3	53	-11%	544	2721	299.31
4/28/2017	4	53	-16%	636	3181	508.96
5/5/2017	5	54	-20%	657	3287	657.4
5/12/2017	6	48	-24%	362	1812	434.88
5/19/2017	7	46	-27%	277	1387	374.49
5/26/2017	8	54	-28%	592	2960	828.8
6/2/2017	9	53	-29%	604	3020	875.8
6/9/2017	10	52	-29%	574	2870	832.3
6/16/2017	11	54	-29%	636	3179	921.91
6/23/2017	12	54	-29%	560	2798	811.42
6/30/2017	13	53	-27%	631	3157	852.39
7/7/2017	14	53	-27%	646	3232	872.64
7/14/2017	15	55	-27%	717	3586	968.22
7/21/2017	16	54	-26%	633	3163	822.38
7/28/2017	17	53	-26%	671	3354	872.04
8/4/2017	18	59	-25%	446	2231	557.75
8/11/2017	19	60	-25%	280	2400	600
8/18/2017	20	61	-25%	660	3313	828.25
Total				**10,724**	**56,788**	**12,854.04**

*(*Delineations of severity are as prescribed in Table 2.2)*

Proactively Calculating Cost of Overtime

Total Cost of Overtime = Cost of Premium Pay + Cost of Loss of Productivity

Cost of Premium Pay = 10,724 X $20/hour = $214,480 ***Cost of Loss of Productivity = Lost hours X Blended Hourly Rate***

Blended Hourly Rate is a weighted base hourly rate for the entire ten hours per day, as a worker is working eight hours under the straight time rate of $40 and 2 hours under the premium pay of $60 per hour.

BLENDED HOURLY RATE = ((8×40)+(2×60))/10 = $44

Cost of Loss of Productivity = 12,854.04 X $44 = $565,577.76 ***Total Cost of Overtime = $214,480+$565,577.76= $780,057.76***

STATISTICAL ANALYSIS OF PRODUCTIVITY FACTORS

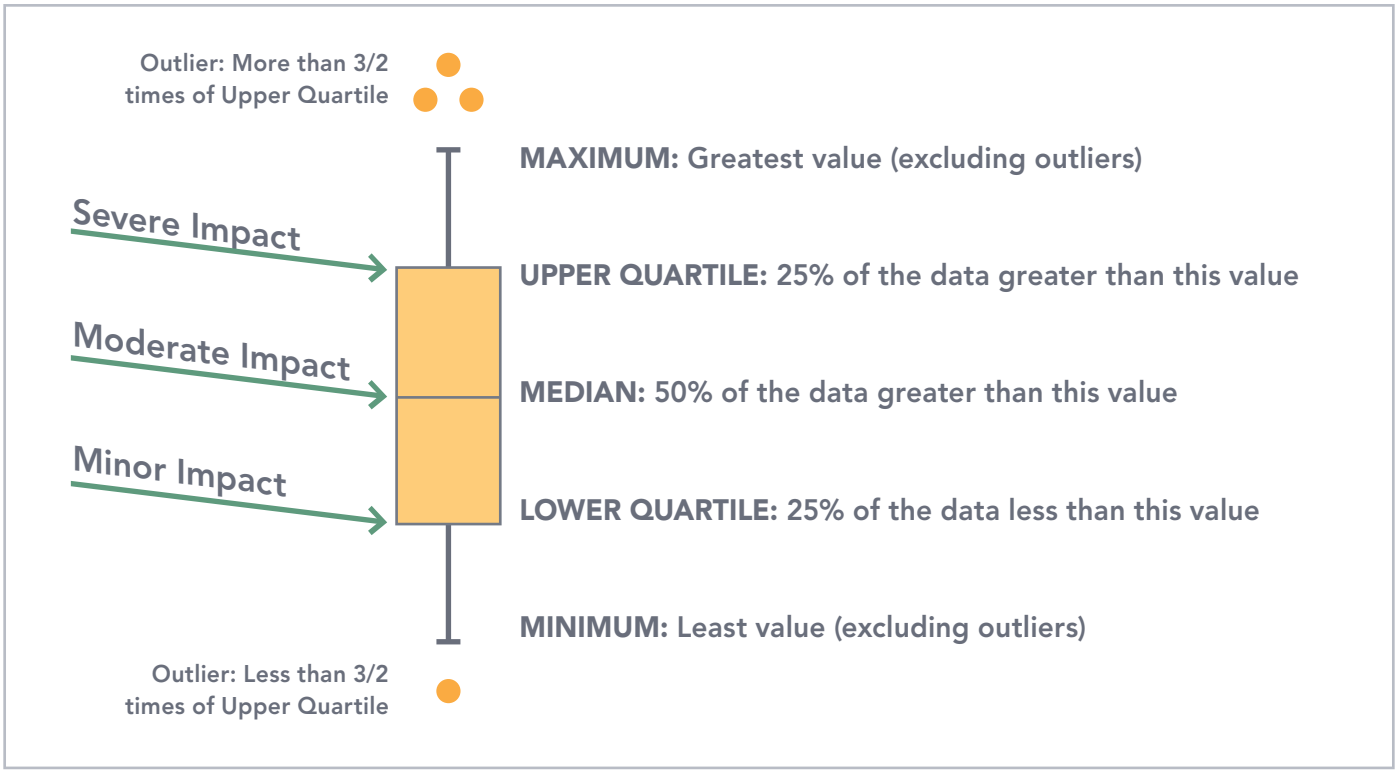
INTRODUCTION

This section provides scientifically quantified impacts of various productivity factors along with each factor's definition. Loss of productivity is represented as minimum, moderate, and severe. This report quantitatively defines the degree of severity of many of these factors. Yet, some productivity factors still need to be subjectively evaluated by contractors. Each factor is represented by a Box Plot (explained below) based on the data collected over the span of this project and is listed in the same sequence found in ***Table 2.1***. These factors can be used proactively or retroactively depending on complete recognition and realization of each factor.

EXPLANATION OF BOX PLOTS

The Box Plot is a statistical tool that depicts the distribution of a set of data in terms of Upper and Lower Limits and Median. In this report, the Box Plot Graph is used to present the degree and the severity of the impact for different productivity factors. A typical Box Plot graph is shown in ***Figure 3.1.*** Within this report, key points are defined as: **Severe impact** (25% of the data above its marker), **Median impact** (50% of the data above its marker), and **Minor impact** (25% of the data below its marker).

Figure 3.1: Example of Box Plot



CUMULATIVE IMPACT

Percentage change is measured as a percentage of change order hours to base contract hours. Change order hours include added scope plus deleted scope. Several research efforts, including one by this author, indicate that contractors should expect up to 10% of change without significant impact on the contractor's labor productivity. When change orders exceed 10%, projects experience what is called cumulative impact. This is the impact on changed and unchanged work (base contract work). Sources of cumulative impact include mobilization and demobilization, stop-and-go, loss of rhythm, loss of momentum, and loss of learning.

Cumulative impact is defined by the Hass & Haynie Corporation as:

> *"Costs associated with impact on distant work, which are not as readily foreseeable or, if foreseeable, not as readily computable as direct impact costs. The source of such costs is the sheer number of and scope of changes to the contract. The result is an unanticipated loss of efficiency and productivity, which increases the contractor's performance costs and usually extends his or her stay on the job."*

QUANTIFICATION OF CUMULATIVE IMPACT

Increased percentage change is a driving factor behind elevated labor inefficiency. However, other factors may increase or decrease labor inefficiency. These factors are:

1. **PERCENTAGE CHANGE —** *the higher the percentage change, the higher the labor inefficiency.*
2. **CHANGE ORDER PROCESSING TIME —** *the period between the initiation of the change order through the RFI (Request for Information) process and the owner approval of the change order(s). Research indicates that with longer processing time comes higher inefficiency.*
3. **OVERMANNING —** *occurs when the peak number of workers divided by the average number of workers exceeds 1.6. Overmanning is typically a result of early delay and added scope of work.*
4. **THE PERCENTAGE OF CHANGE ORDERS RELATED TO DESIGN ISSUES —** *the two major sources of change orders are added scope and design issues including design errors, design coordination, and design change. Research shows that the higher the percentage of design issues, the higher the labor inefficiency. Additionally, change orders related to design have more impact than change orders related to added scope.*

Research conducted by this author shows increased inefficiency correlated with increased percentage change. However, there are other factors, as mentioned above that, when combined with higher percentage change, cause higher values of inefficiency. The summary of this research is graphically displayed in figures 3.2-3.4. These figures show change order impact on labor inefficiency.

Figure 3.2 demonstrates the impact of percentage change, OVERMANNING ((ACTUAL PEAK)/(PLANNED AVERAGE) > 4), and longer change order processing time (more than 5 weeks) on labor inefficiency.

Figure 3.3 displays the impact of percentage change, OVERMANNING (3 < (ACTUAL PEAK)/(PLANNED AVERAGE) < 4), and longer processing time (more than 3 weeks) on labor inefficiency.

Figure 3.4 shows the relationship between percentage change, OVERMANNING (1.6 < (ACTUAL PEAK)/(PLANNED AVERAGE) < 3), longer processing time (less than 3 weeks) and labor inefficiency.

Figures 3.2-3.4 also show upper and lower confidence intervals at 95 percent. To explain the meaning of these intervals, refer to Figure 3.3. Suppose the contractor experiences 60 percent change. The corresponding loss of productivity is 40 percent. Contractors can say with 95% confidence that they are likely to experience a loss of productivity between approximately 38% and 42% of the total actual hours utilized at the end of the project, including change order hours.

In Figures 3.2, 3.3, and 3.4, the dark solid vertical lines show the range of applicability for these graphs. For example, Figure 3.2 can only be used when percentage change is greater than 10% and less than 100%. Similarly, Figures 3.3 and 3.4 can only be used when percentage change is greater than 10% and less than 110%.

Figure 3.2: Change Order Impact Plus Overmanning and Very Long Processing Time (>5 Weeks)

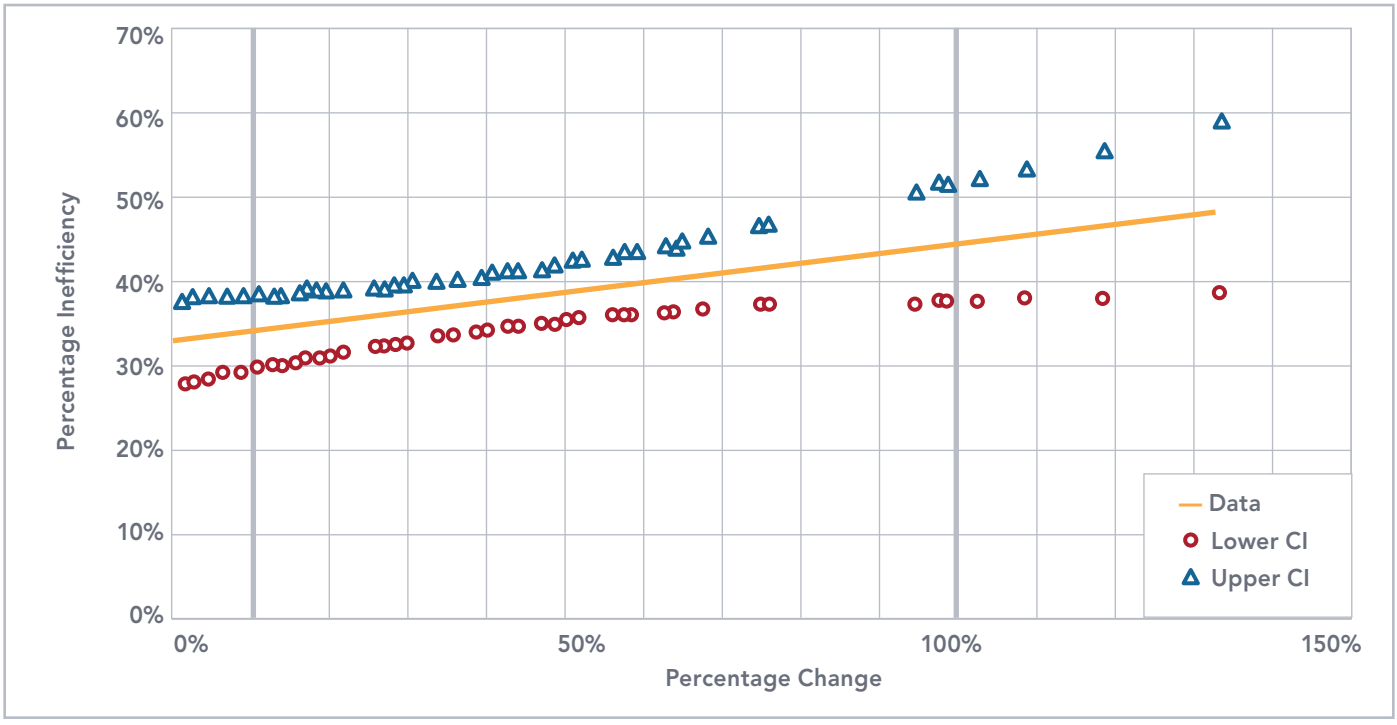


Figure 3.3: Change Order Impact Plus Overmanning and Long Processing Time (3 to 5 Weeks)

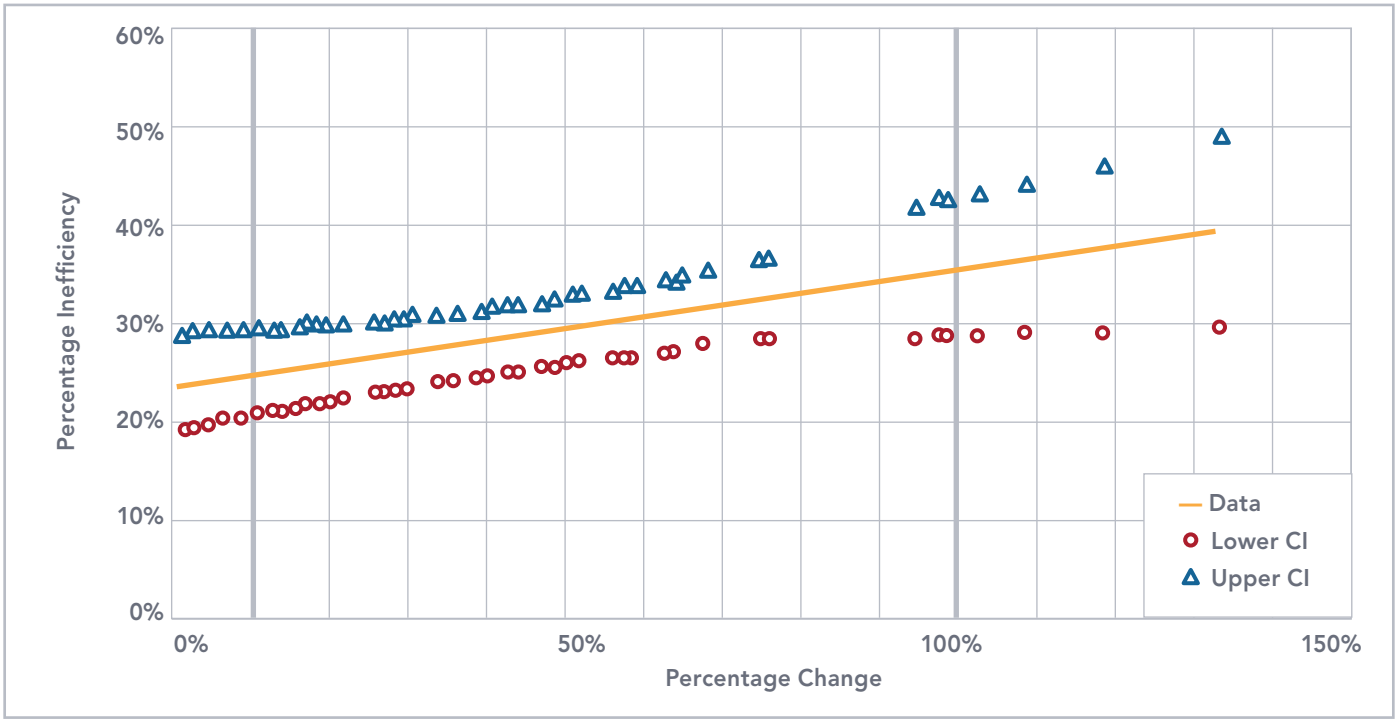
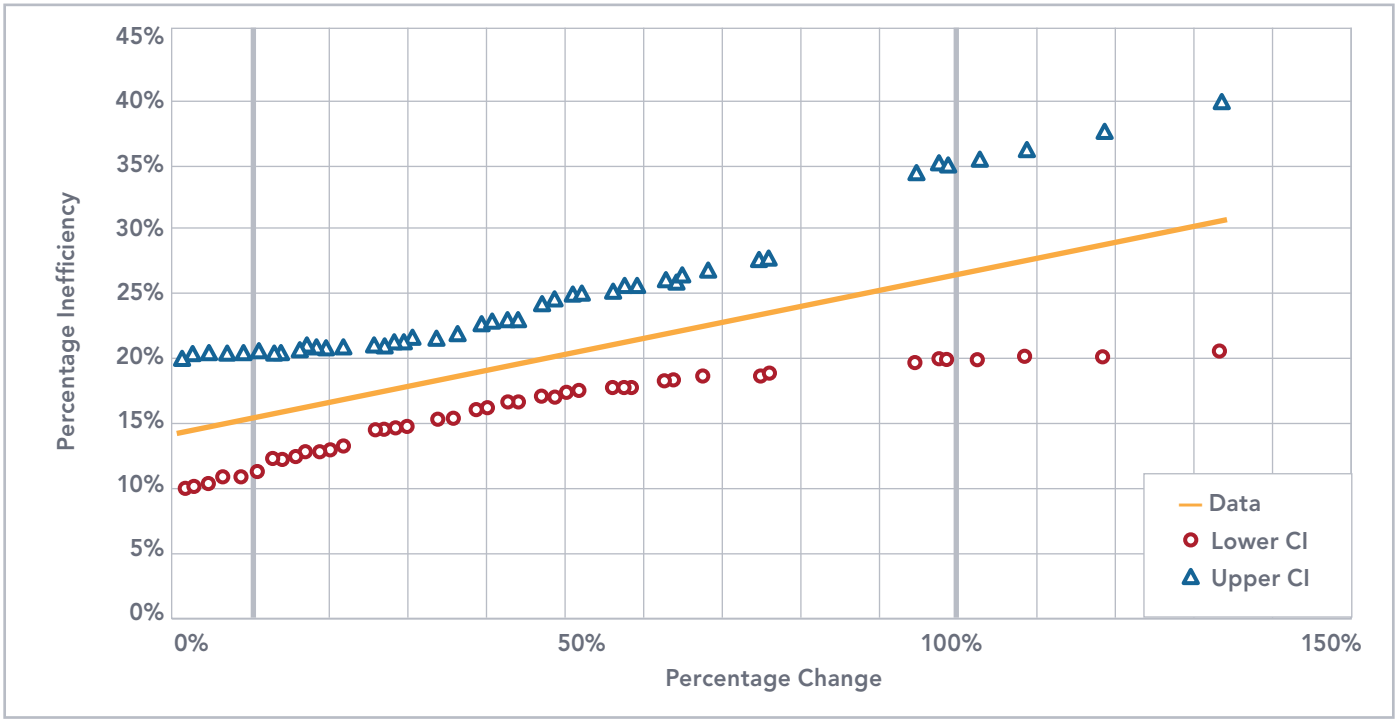


Figure 3.4: Change Order Impact Plus Overmanning and Average Processing Time (<3 Weeks)



OVERMANNING

Overmanning can be defined in two ways. First, it can be defined as increasing the number of labor crews above optimum. The optimum number of labor crews is the minimum number of workers required to perform the task within the allocated timeframe. Second, overmanning can be defined when the ratio of the actual peak number of workers of the same trade divided by the planned average number of workers exceeds 1.6. This second definition is used in this report to quantify the impact of overmanning.

Inefficiencies due to overmanning affect many different aspects of construction. In terms of the location, a high density of laborers can cause congestion because of insufficient work space. An increased number of workers can also cause materials, tools, and equipment to run short. The attention and efficiency of supervisors can become overwhelmed by the task of coordinating and controlling workers, resulting in increased supervision costs.

Figure 3.5 below shows the productivity loss for three levels of overmanning:

Level 1 is minimum impact:

$$1.6 < \frac{\text{ACTUAL PEAK}}{\text{PLANNED AVERAGE}} < 3$$

Level 2 is moderate impact:

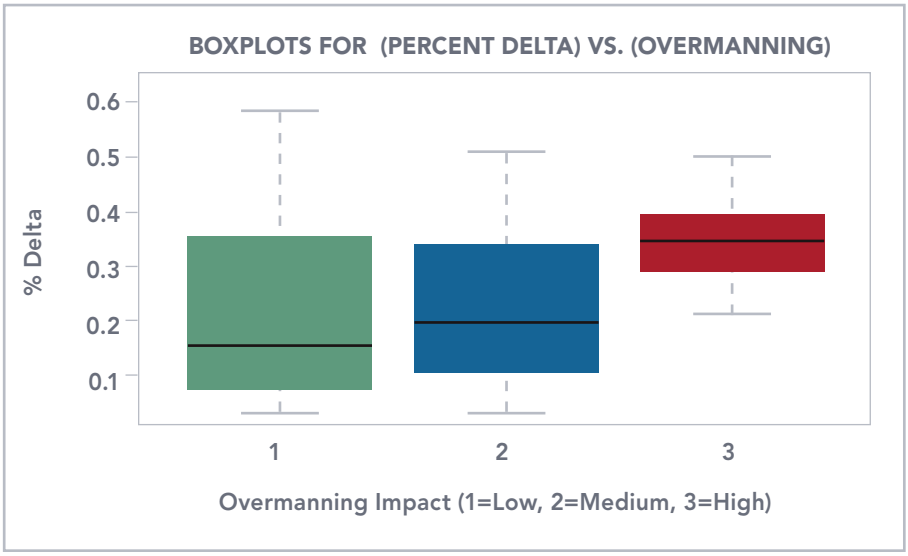
$$3 < \frac{\text{ACTUAL PEAK}}{\text{PLANNED AVERAGE}} < 4$$

Level 3 is severe impact:

$$\frac{\text{ACTUAL PEAK}}{\text{PLANNED AVERAGE}} > 4$$

Figure 3.5: Boxplots for Impact of Overmanning

Severity Level	Median Value
Low (Minor)	15%
Medium (Moderate)	19%
High (Severe)	33%



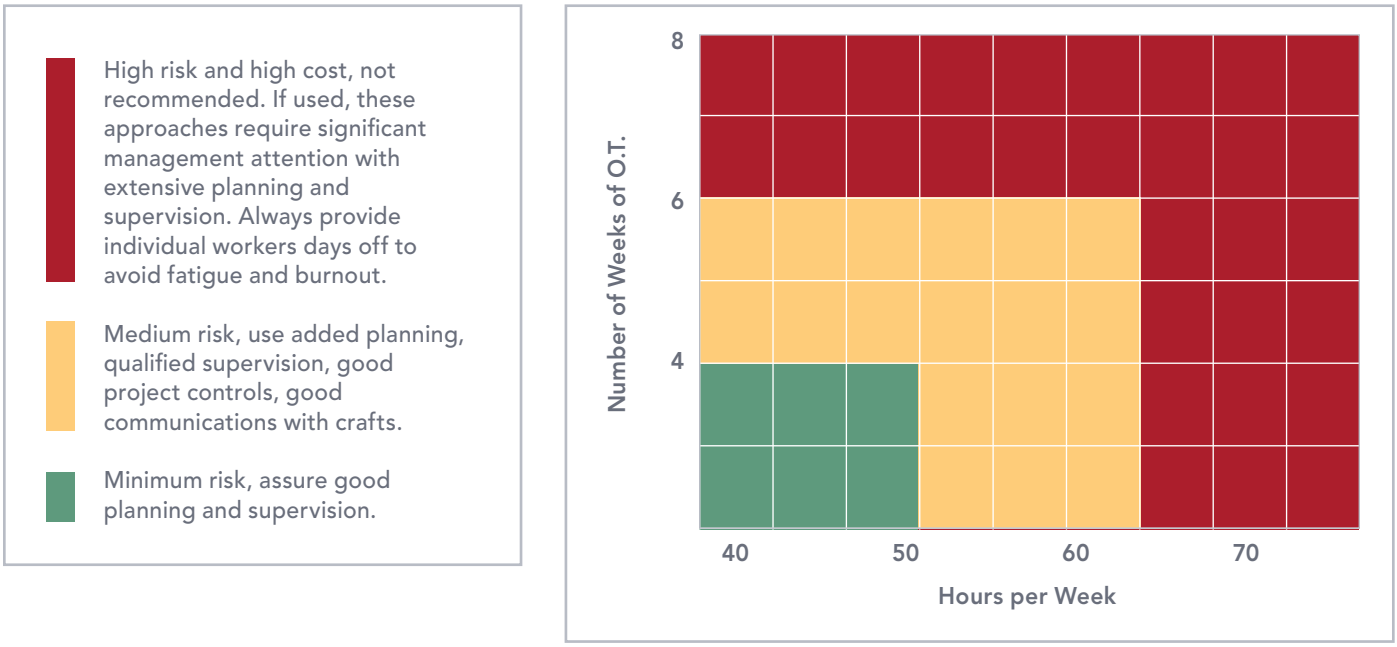
OVERTIME

Overtime is defined as any hour worked after eight hours per day and/or any hours worked after 40 hours per week. Overtime can occur in a variety of schedules including five days of 10 hours worked/day (5X10), 6X10, 7X10, 7X12. Overtime can also be sporadic. For example, a worker can work 10 hours one day, 12 hours a second day, and 9 hours the third and fourth days, and 8 hours on the fifth day. Although some days the worker works regular hours, the week's total is more than 40 hours.

Contractors often implement overtime in response to increased scope, accelerated schedules, good weather, and to maximize equipment use. **Loss of productivity as a result of overtime can be attributed to the following factors:**

1. **FATIGUE:** *Workers are accustomed to working 40 hours per week. Increased work hours can cause fatigue, which can negatively impact productivity, morale, and safety.*
2. **ABSENTEEISM**: *Fatigue can result in absenteeism. Research has indicated a direct correlation between an extensive use of overtime and a higher percentage of absenteeism.*
3. **PACING:** *Workers tend to pace their efforts to adjust for a longer day or week. When work hours are extended, workers tend to adjust the pace subconsciously to accomplish the same amount of work as they would in a typical 8-hour day.*

Figure 3.6: Risk of Prolonged Overtime



THE FOUR PRINCIPAL OVERTIME SCHEDULES

In modern construction, aggressive scheduling practices have led to using overtime more frequently than in the past. Contractors use different overtime scheduling techniques, depending on multiple factors such as project type, site access, etc. However, contractors generally work overtime on a 5x10, 6x10, 7x10 or 7x12 schedule. Each type of schedule produces diminishing returns of productivity over time. However, the rate at which productivity degrades is different between schedules. Below, in figures 3.7 to 3.10, the cumulative productivity of each schedule is depicted graphically. It should be noted that, as shown below, 7x10 shows a greater loss of productivity than 7x12, which is counterintuitive. The reason for this idiosyncrasy is that the cases studied rotated crews off the project after several weeks of 7x12 overtime, allowing them a longer period to rest and recover, thus maintaining morale while working longer hours.

Figure 3.7: Cumulative Productivity of 5x10 Schedule

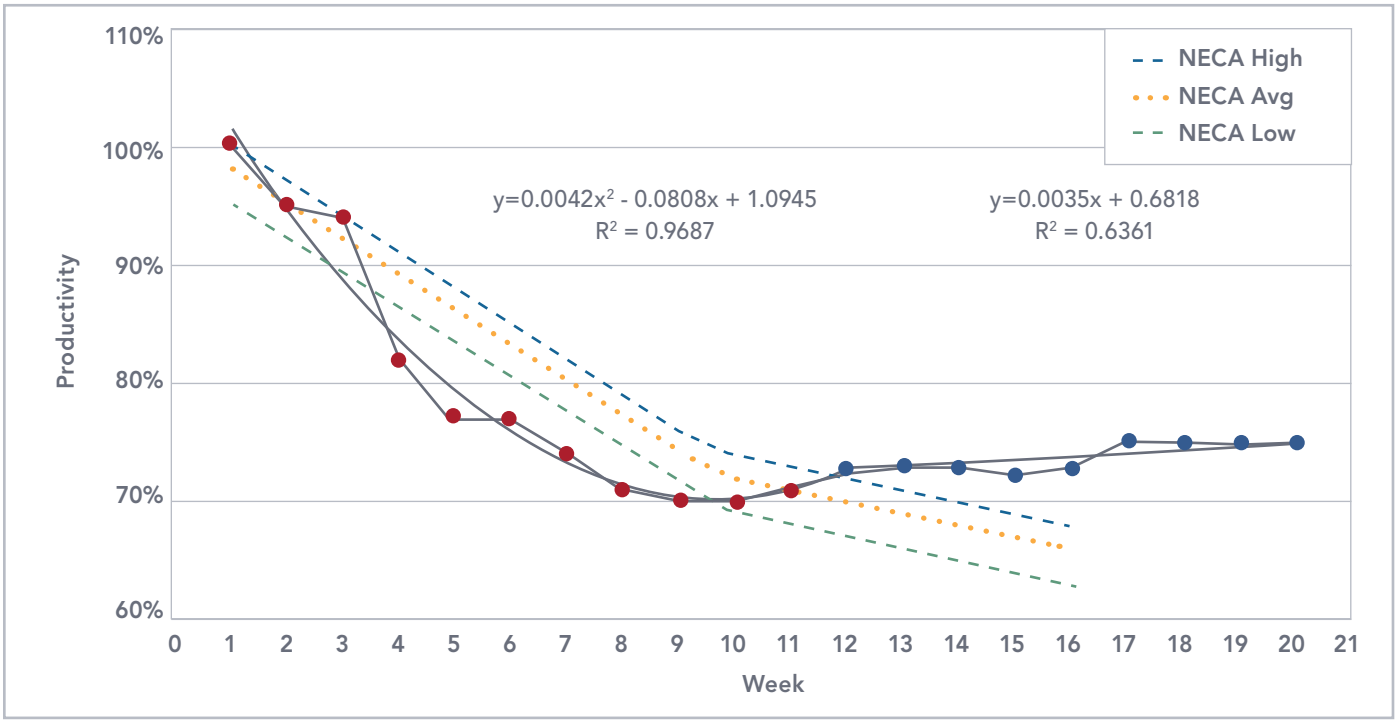


Figure 3.8: Cumulative Productivity of 6x10 Schedule

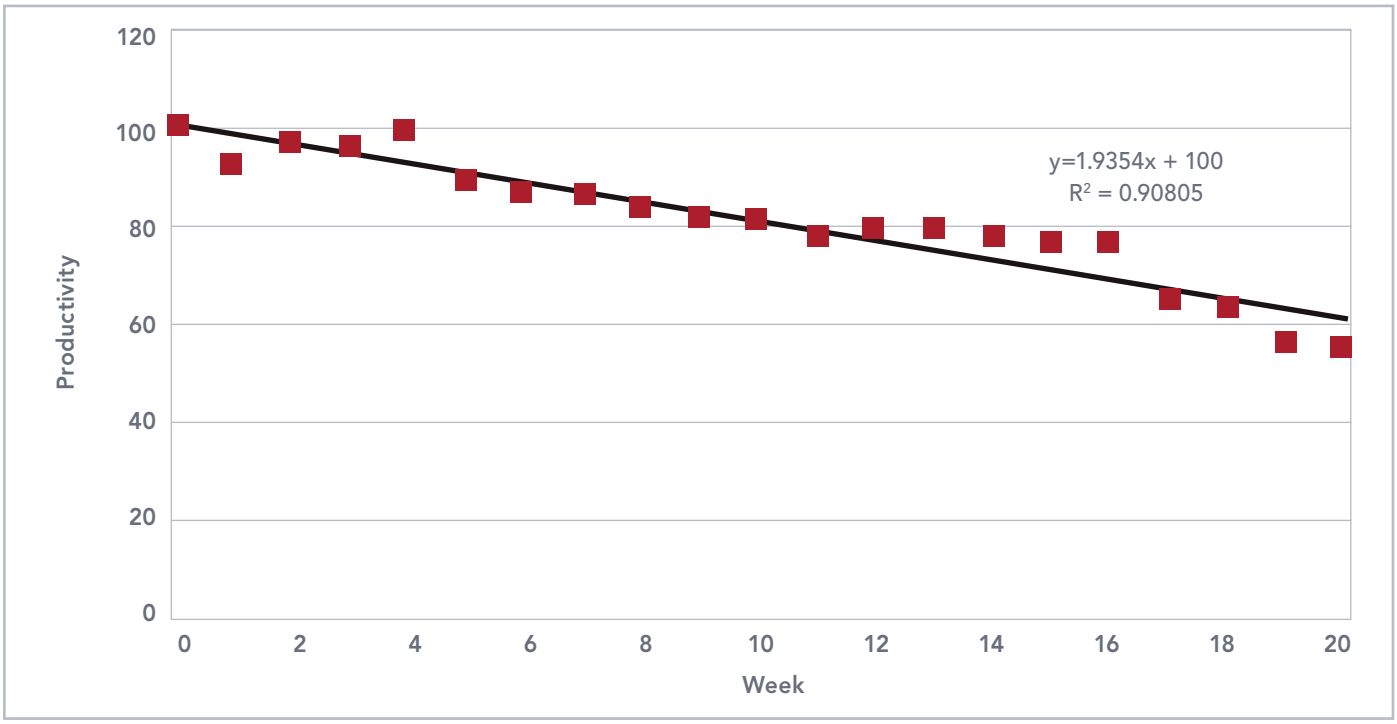


Figure 3.9: Cumulative Productivity of 7x10 Schedule

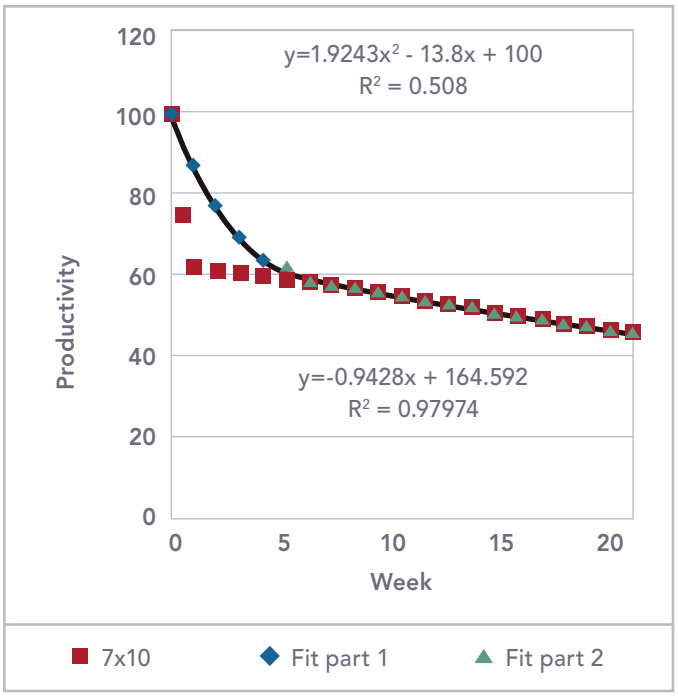
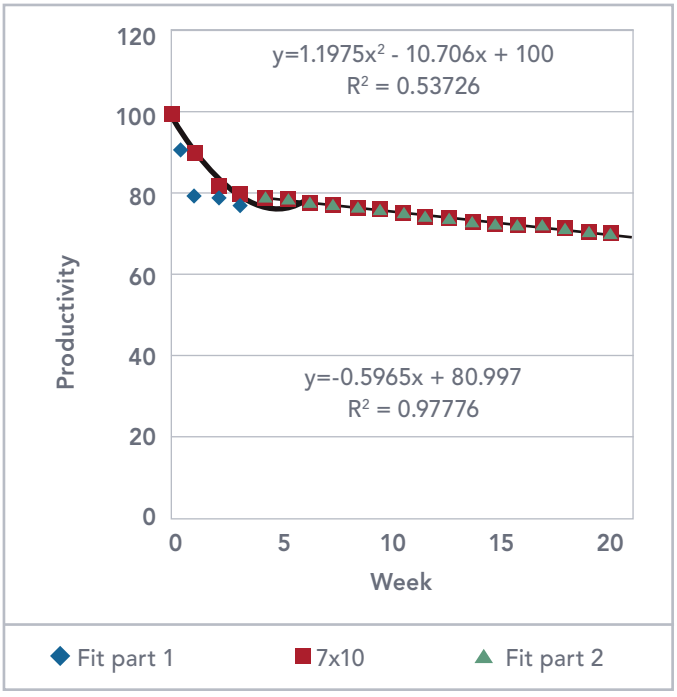


Figure 3.10: Cumulative Productivity of 7x12 Schedule



SECOND SHIFT/SHIFT WORK

Shift work is defined as the hours worked by a second group of craftsmen whose work on a project is performed after the primary workforce of the same trade has finished for the day. A second shift experiences no significant overlap of hours during which its craftsmen are working in conjunction with members of the first shift.

The use of shift work usually allows projects to avoid the inefficiencies that result from physical fatigue caused by overtime, although shift work can generate its own types of inefficiency, attributable to the following:

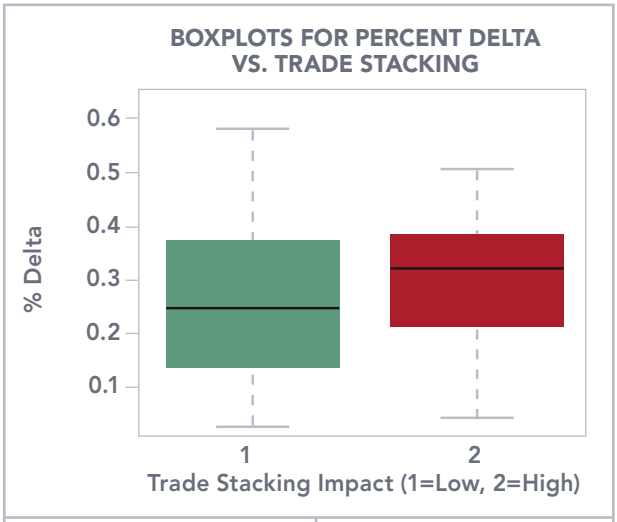
- **1.** *The transition from one shift to another.*
- **2.** *A lack of a single point of responsibility for progress and quality.*
- **3.** *Extensive worker coordination, increased absenteeism and turnover, and increased error and accidents as a result of the disruption of normal sleeping hours.*
- **4.** *Unavailability of timely administrative decisions from higher management.*
- **5.** *Potential for higher accident rate as a result of artificial lighting.*
- **6.** *Light trespassing and noise impact on nearby residents.*
- **7.** *Increased cost of support staff such as a crane operator.*

STACKING OF TRADES

The stacking of trades (also known as overcrowding) is defined as the total number of craftsmen from all trades working in a given area. This term describes project conditions where multiple trades are working simultaneously in a single work area. Stacking of Trades is a common secondary effect of multiple contractors responding to schedule acceleration with Overmanning, though it can and does occur under normal conditions as well.

Having too many workers in a single area decreases the square foot density available to each craftsman and, therefore, has a negative impact on labor productivity. Construction requires that workers have their tools and materials in close proximity, along with enough room to maneuver if they are asked to perform a task. Stacking creates congestion and crew interference as workers must navigate around each other and find space to store tools and materials. This negatively impacts productivity.

Figure 3.11: Trade Stacking Box Plot



Severity Level	Median Value
Low (Minor)	24%
High (Severe)	32%

Various researchers have addressed this topic, and the consensus is that a minimum of 150 to 300 sq. ft. is needed per worker for full productivity, depending on the complexity of the work. Most of the literature more concisely defines 200 to 250 sq. ft. per worker as the minimum.

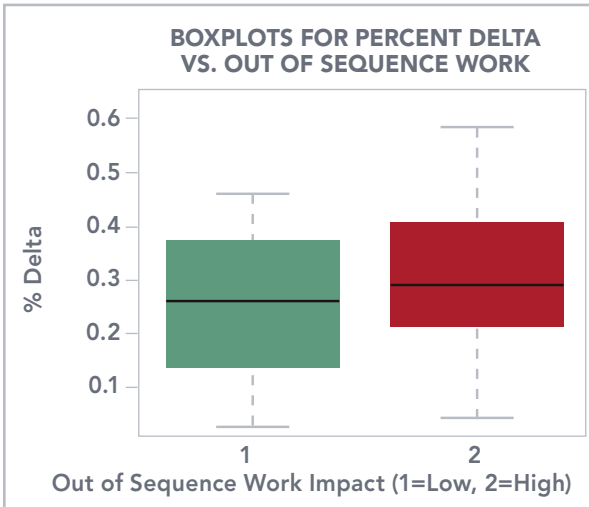
OUT OF SEQUENCE WORK

Out of sequence work is defined as an activity or series of activities not performed according to baseline logical and optimal planned sequences.

Out of sequence work can be caused by poor coordination between trades, inadequate A/E support during construction, delay in delivery of major equipment, and lack of involvement of key participants in both design and construction stages.

Inefficiencies caused by out of sequence work may include an impact on cost and schedules, productivity, safety, and quality. Research has shown an increase in project cost and schedule delay by the increase of frequency and number of out of sequence work events. In addition, out of sequence work has an impact on quality in terms of the increased number of drawings, nonconformity reports, and increased cost of punch list items.

Figure 3.12: Out of Sequence Work Box Plot



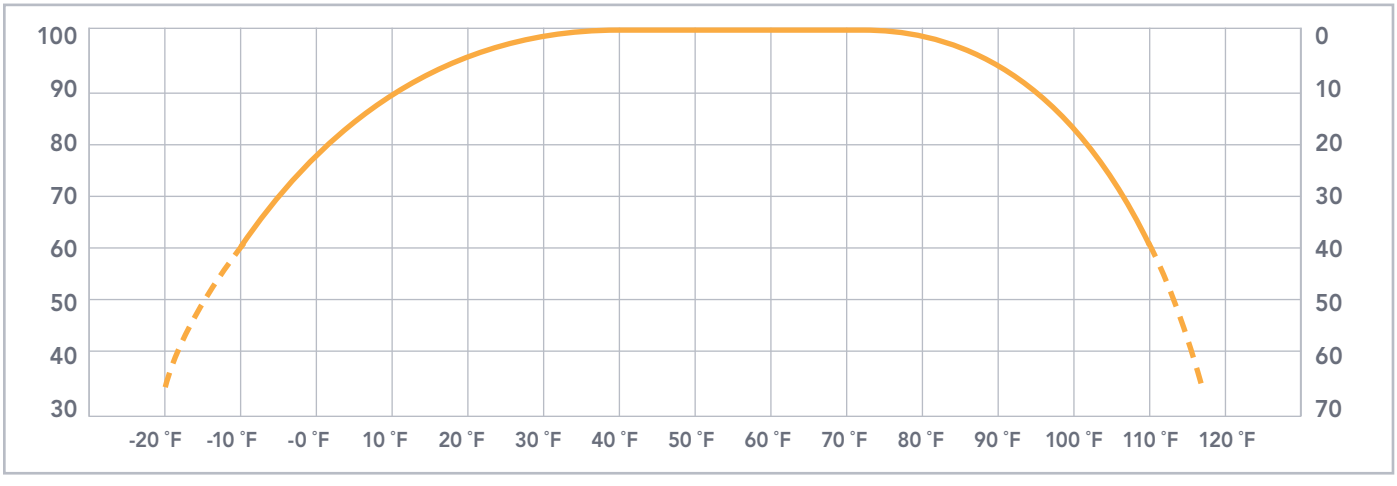
Severity Level	Median Value
Low (Minor)	26%
High (Severe)	29%

WEATHER

Hot, cold, and humid weather conditions have a negative impact on labor productivity. Ideal temperatures for construction work range from 40-80˚F. Productivity declines on both sides of that range. **Significant productivity loss of 40% is realized at -10 ˚F and 110 ˚F.**

Evidence of the negative impacts of weather on labor productivity may include fatigue, the need to wear protective clothing, errors in judgment, more frequent breaks, and the use of unusual work hours.

Figure 3.13: Impact of Temperature on Labor Productivity



OWNER-FURNISHED ITEMS

Owner-furnished items include both materials and equipment that are bought by the owner or the owner-agent (such as the general contractor) to save on the sub-contractor's markup or to have a head start on acquiring equipment that needs long lead times.

Because owner-furnished items fall outside the direct control of the contractor, they can negatively impact productivity through their late delivery, damaged delivery, maintenance, and handling. The lack of direct control over the flow of necessary materials to the worksite can force contractors to perform work out of sequence or to accelerate the schedule in other detrimental ways.

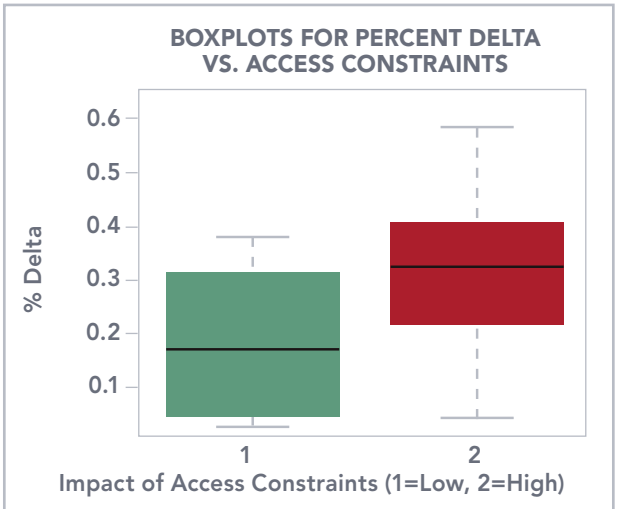
Table 3.1: Impact of Owner Furnished Items on Labor Productivity

	MATERIALS																			
EQUIPMENT	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**	**55%**	**60%**	**65%**	**70%**	**75%**	**80%**	**85%**	**90%**	**95%**	**100%**
5%	4.3%	4.7%	5.0%	5.1%	5.3%	5.4%	5.5%	5.6%	5.7%	5.8%	5.8%	5.9%	5.9%	6.0%	6.1%	6.1%	6.1%	6.2%	6.2%	6.3%
10%	5.5%	6.0%	6.3%	6.5%	6.7%	6.9%	7.0%	7.1%	7.2%	7.3%	7.4%	7.5%	7.6%	7.6%	7.7%	7.8%	7.8%	7.9%	7.9%	8.0%
15%	6.3%	6.9%	7.3%	7.5%	7.8%	7.9%	8.1%	8.2%	8.3%	8.5%	8.6%	8.6%	8.7%	8.8%	8.9%	9.0%	9.0%	9.1%	9.2%	9.2%
20%	7.0%	7.6%	8.0%	8.3%	8.6%	8.8%	8.9%	9.1%	9.2%	9.3%	9.5%	9.6%	9.7%	9.8%	9.8%	9.9%	10.0%	10.1%	10.1%	10.2%
25%	7.6%	8.3%	8.7%	9.0%	9.3%	9.5%	9.7%	9.8%	10.0%	10.1%	10.2%	10.3%	10.4%	10.5%	10.6%	10.7%	10.8%	10.9%	11.0%	11.0%
30%	8.1%	8.8%	9.3%	9.6%	9.9%	10.1%	10.3%	10.5%	10.6%	10.8%	10.9%	11.0%	11.1%	11.2%	11.3%	11.4%	11.5%	11.6%	11.7%	11.7%
35%	8.5%	9.3%	9.8%	10.1%	10.4%	10.7%	10.9%	11.1%	11.2%	11.4%	11.5%	11.6%	11.8%	11.9%	12.0%	12.1%	12.2%	12.2%	12.3%	12.4%
40%	8.9%	9.7%	10.3%	10.6%	10.9%	11.2%	11.4%	11.6%	11.8%	11.9%	12.1%	12.2%	12.3%	12.4%	12.5%	12.6%	12.7%	12.8%	12.9%	13.0%
45%	9.3%	10.2%	10.7%	11.1%	11.4%	11.6%	11.9%	12.1%	12.3%	12.4%	12.6%	12.7%	12.8%	13.0%	13.1%	13.2%	13.3%	13.4%	13.5%	13.5%
50%	9.7%	10.5%	11.1%	11.5%	11.8%	12.1%	12.3%	12.5%	12.7%	12.9%	13.0%	13.2%	13.3%	13.4%	13.6%	13.7%	13.8%	13.9%	14.0%	14.0%
55%	10.0%	10.9%	11.5%	11.9%	12.2%	12.5%	12.7%	13.0%	13.1%	13.3%	13.5%	13.6%	13.8%	13.9%	14.0%	14.1%	14.2%	14.3%	14.4%	14.5%
60%	10.3%	11.2%	11.8%	12.2%	12.6%	12.9%	13.1%	13.4%	13.6%	13.7%	13.9%	14.0%	14.2%	14.3%	14.4%	14.6%	14.7%	14.8%	14.9%	15.0%
65%	10.6%	11.5%	12.1%	12.6%	13.0%	13.2%	13.5%	13.7%	13.9%	14.1%	14.3%	14.4%	14.6%	14.7%	14.9%	15.0%	15.1%	15.2%	15.3%	15.4%
70%	10.9%	11.9%	12.5%	12.9%	13.3%	13.6%	13.9%	14.1%	14.3%	14.5%	14.7%	14.8%	15.0%	15.1%	15.2%	15.4%	15.5%	15.6%	15.7%	15.8%
75%	11.1%	12.1%	12.8%	13.2%	13.6%	13.9%	14.2%	14.4%	14.7%	14.8%	15.0%	15.2%	15.3%	15.5%	15.6%	15.7%	15.9%	16.0%	16.1%	16.2%
80%	11.4%	12.4%	13.1%	13.5%	13.9%	14.2%	14.5%	14.8%	15.0%	15.2%	15.4%	15.5%	15.7%	15.8%	16.0%	16.1%	16.2%	16.3%	16.5%	16.6%
85%	11.6%	12.7%	13.3%	13.8%	14.2%	14.6%	14.8%	15.1%	15.3%	15.5%	15.7%	15.9%	16.0%	16.2%	16.3%	16.5%	16.6%	16.7%	16.8%	16.9%
90%	11.9%	12.9%	13.6%	14.1%	14.5%	14.8%	15.1%	15.4%	15.6%	15.8%	16.0%	16.2%	16.4%	16.5%	16.6%	16.8%	16.9%	17.0%	17.1%	17.3%
95%	12.1%	13.2%	13.9%	14.4%	14.8%	15.1%	15.4%	15.7%	15.9%	16.1%	16.3%	16.5%	16.7%	16.8%	17.0%	17.1%	17.2%	17.4%	17.5%	17.6%
100%	12.3%	13.4%	14.1%	14.6%	15.1%	15.4%	15.7%	16.0%	16.2%	16.4%	16.6%	16.8%	17.0%	17.1%	17.3%	17.4%	17.5%	17.7%	17.8%	17.9%

ACCESS CONSTRAINTS

Access constraints occur when the contractor has inadequate, partial or no access to the work area. These constraints can be caused by poor materials, storage and staging practices, working on and around an operating unit, and incomplete or partially completed preceding activities. Productivity loss occurs when the contractor must visit the work area multiple times as more work becomes available.

Figure 3.14: Access Constraints Box Plot



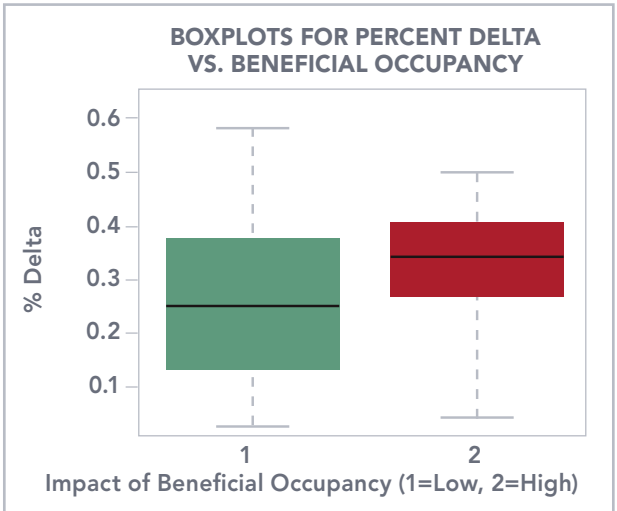
Severity Level	Median Value
Low (Minor)	17%
High (Severe)	32%

BENEFICIAL OCCUPANCY

Beneficial occupancy describes the situation in which a contractor must work in close proximity to an owner's production equipment or personnel. An example of beneficial occupancy would be performing construction in a factory with an operational production line running the length of the facility. Contractors must adjust to environmental circumstances including extra safety precautions, concerns regarding dust or noise, and the reduction or absence of a convenient material laydown area. Conditions of beneficial occupancy diminish labor productivity through no direct fault of the contractor. Nevertheless, the estimate and contract must be adjusted for the nature of the work.

The situation of beneficial occupancy also occurs when construction must be performed around the owner's personnel or production equipment. Working in these conditions raises issues such as the safety of non-contractor personnel and special noise and dust considerations, along with a reduction in the speed of the craftsmen. When special care and consideration must be taken, the overall efficiency of the project labor in a beneficially occupied area is reduced. Most important, however, is the loss of laydown space for a contractor's materials and tools. If craftsmen must keep the items needed for their work in locales that are inconvenient or far away, time is lost, which equates to lost productivity.

Figure 3.15: Beneficial Occupancy Boxplot

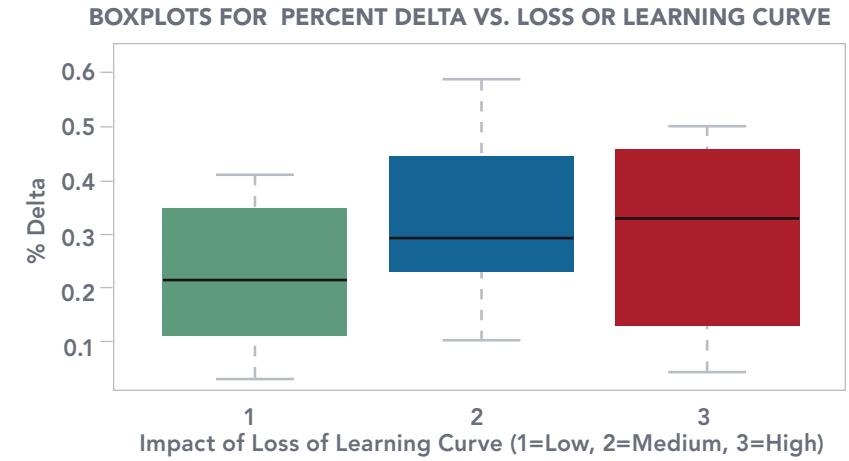


Severity Level	Median Value
Low (Minor)	25%
High (Severe)	34%

LOSS OF LEARNING

The learning curve theory is well-established in both the manufacturing and construction industries. The theory states that repetition shortens the time it takes to complete a given task. For the learning to occur, the same task must be performed with the same workers without interruption. If there is a delay between repetitive activities the "unlearning" impact will be noted.

Figure 3.16: Loss of Learning Box Plot



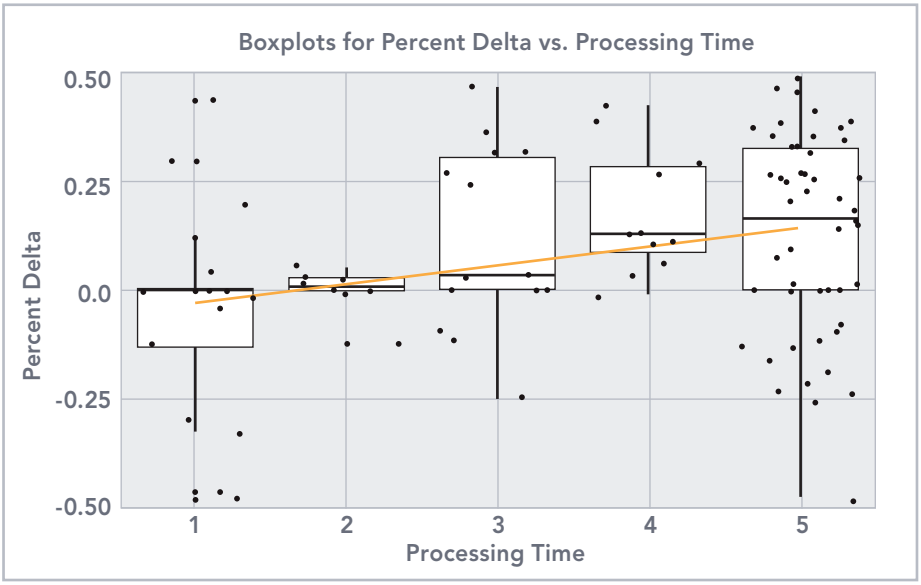
Severity Level	Low (Minor)	Medium (Moderate)	High (Severe)
Median Value	21%	29%	32%

CHANGE ORDER PROCESSING TIME

Change Order Processing Time is the period of time between initiation of the change order and the owner's approval of the change order for the majority of change items. If the processing time is long, workers will leave certain areas unfinished until the information required to finish the work is received. ***Figure 3.17*** below shows the decrease in labor productivity as the processing time increases. It is a recommended practice to keep the processing time to less than one week.

Figure 3.17: Change Order Processing Time Box Plot

Severity Level	Median Value
Low (Minor)	0%
Medium (Moderate)	10%
High (Severe)	15%



MORALE & ATTITUDE

There is a strong correlation between the morale and attitude of the work force to project conditions as reflected by the degree of absenteeism and turnover. Absenteeism is measured as the ratio between the number of craft workers who failed to appear for work and the number of craft workers employed on a project. Similarly, the turnover ratio is defined as the number of craft workers hired to replace those who have left compared to the number of craft workers employed on a project. It was observed that the percent of absenteeism and turnover is higher for projects that experienced delays, multiple changes, and other disruptions.

Absenteeism impacts crew balance in terms of the number of people required to perform certain tasks. Higher turnover ratios require hiring replacement workers who then need time to become familiar with the job conditions and to perform at the optimal level of productivity. ***Figures 3.18*** and ***3.19*** below contain box plots illustrating these values.

Figure 3.18: Absenteeism Boxplots

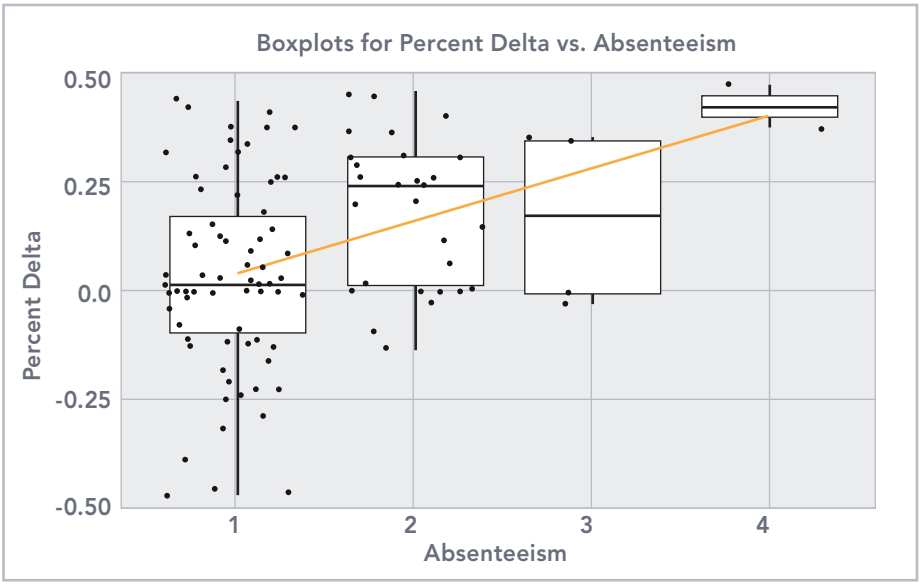
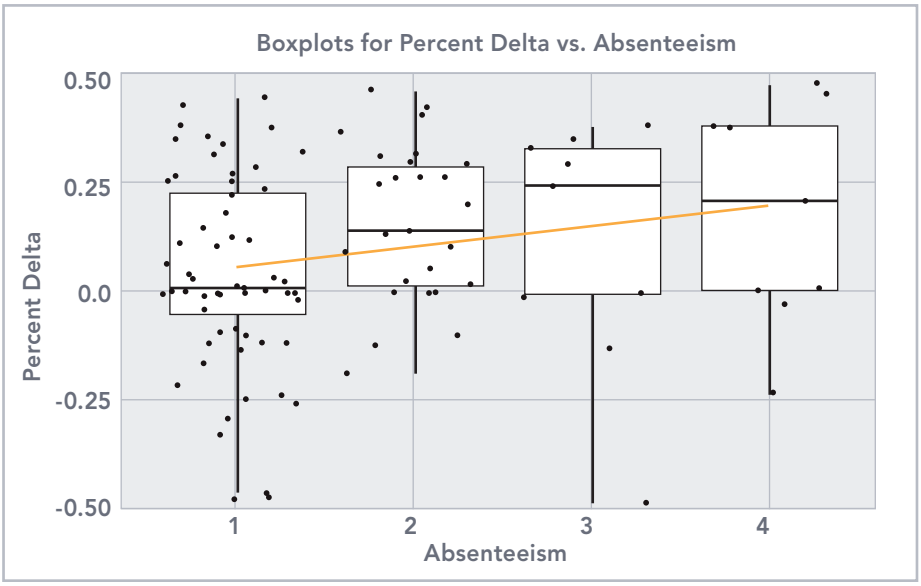


Figure 3.19: Turnover Boxplots

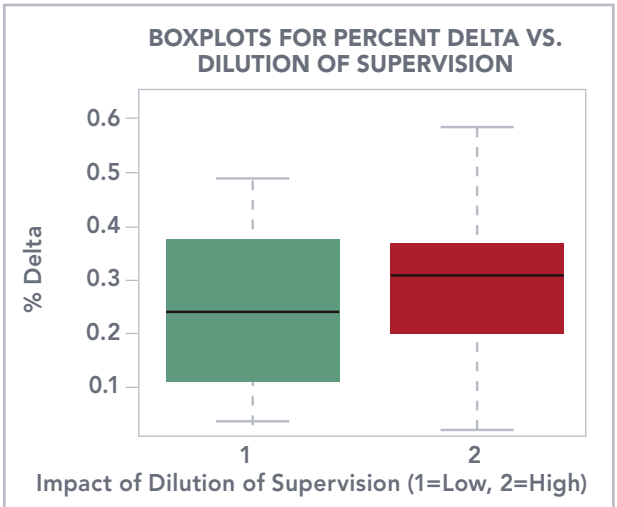
Severity Level	Absenteeism Median Value	Turnover Median Value
Low (Minor)	2%	4%
Medium (Moderate)	22%	10%
High (Severe)	40%	20%



DILUTION OF SUPERVISION

The dilution of supervision frequently occurs when additional work is requested and supervisors must manage both changed and unchanged work. As a result, they become ineffective in two separate areas instead of being productive in the one originally-planned area. This can also occur when multiple changes need to be made. The supervisor must first study them, then communicate to the crew, order and expedite materials, acquire the necessary tools, and review safety practices for the changed items. The source of inefficiency from the dilution of supervision occurs when the supervisor becomes a bottleneck of decision-making for the crew. ***Figure 3.20*** below contains box plots illustrating these values.

Figure 3.20: Boxplots for Dilution of Supervision



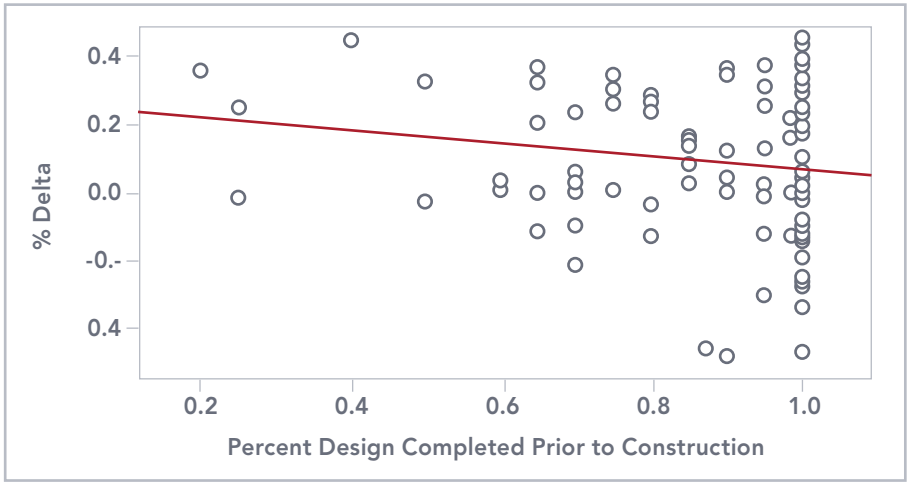
Severity Level	Median Value
Low (Minor)	25%
High (Severe)	31%

PERCENT DESIGN COMPLETE PRIOR TO CONSTRUCTION

As a result of the fast-track nature of today's construction projects, it is not uncommon for contractors to bid for documents that are 80% complete or less. Under fast-track, it is typical for the design engineer to release the design document prematurely in order to establish the total project budget. Incomplete designs lead to a high frequency of Requests for Information (RFI) that require workers to have multiple visits to the same work location as more information becomes available. Each time a worker must visit the same work location more than once, productivity suffers as a result of stop-and-go, mobilization and demobilization, loss of rhythm, and loss of learning.

Figure 3.21: Impact of Design Completion Prior to Construction on Labor Productivity

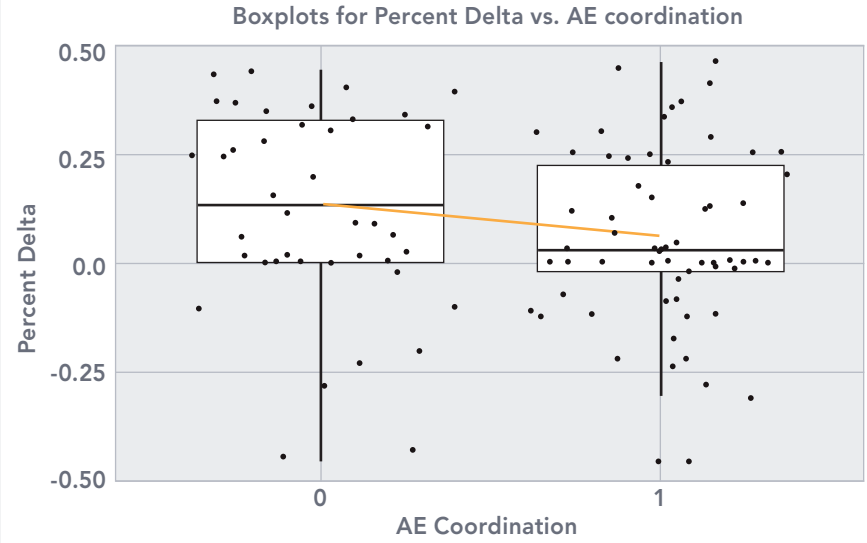
Severity Level	Median Value
Low (Minor)	1%
Medium (Moderate)	10%
High (Severe)	18%



AE COORDINATION PRIOR TO CONSTRUCTION

It is very important for design professionals to coordinate their drawings with each other to avoid collision between systems and inadequate space for installation.

Figure 3.22: Impact of AE Coordination on Labor Productivity

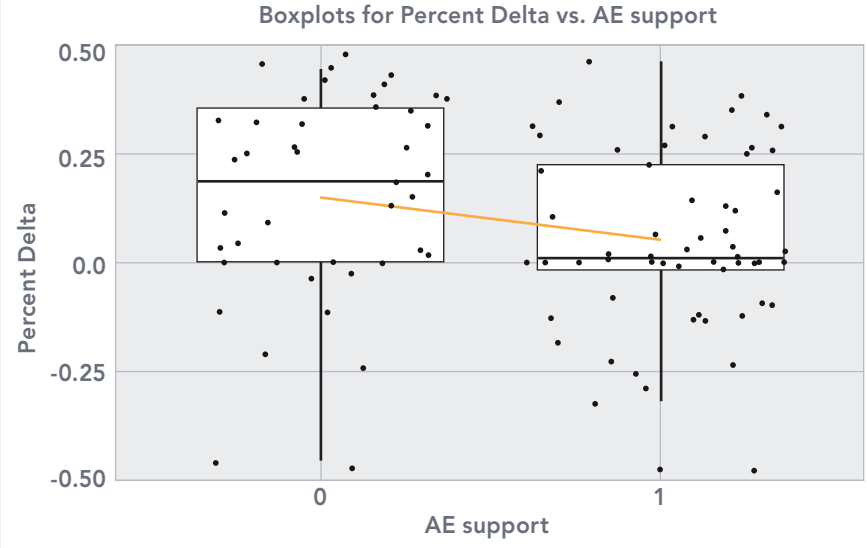


Severity Level	Low (Minor)	Medium (Moderate)	High (Severe)
Median Value	2%	8%	14%

AE SUPPORT DURING CONSTRUCTION

It is important for design professionals to provide adequate support to contractors during construction. This support includes collision analysis and adequate and fast response to RFI's.

Figure 3.23: Impact of AE Support during Construction on Labor Productivity



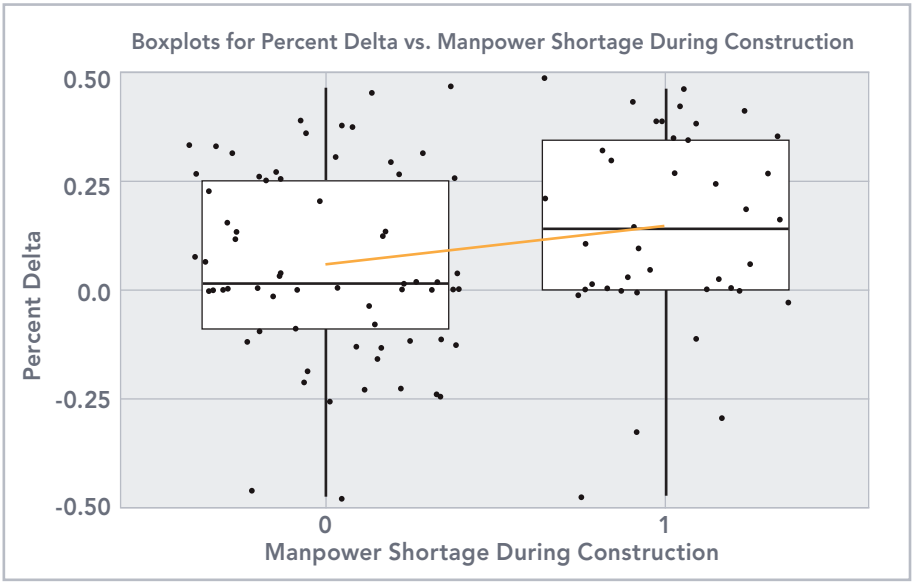
Severity Level	Low (Minor)	Medium (Moderate)	High (Severe)
Median Value	1%	10%	20%

MANPOWER SHORTAGE

Frequently, contractors are forced to hire less-qualified workers in the busy construction market, with hiring often compounded by an increase in project scope. In a union environment, worker shortage can be measured by the percent of employment in the union hall.

Figure 3.24: Impact of Manpower Shortage during Construction on Labor Productivity

Severity Level	Median Value
Low (Minor)	2%
Medium (Moderate)	8%
High (Severe)	14%



APPENDIX 1: DEFINITIONS OF TERMS

ABSENTEEISM

is the ratio between the number of craftsmen who fail to appear for work to the number of craftsmen employed for a project.

AVERAGE MANPOWER

is the average number of craftsmen used on the project at any point in time. This can be mathematically estimated by taking the Total Manhours for the Project divided by the Duration (in weeks) and the Average Hours Worked Per Week Per Craftsman.

BENEFICIAL OCCUPANCY

is a situation in which a contractor must work in close proximity to an owner's production equipment or personnel, requiring the contractor to adjust to environmental circumstances, including extra safety precautions, concerns of dust or noise, and the reduction or absence of a convenient material laydown area.

CUMULATIVE IMPACT

occurs when the costs associated with impact on distant work, (not as readily foreseeable) or, if foreseeable, not as readily computable as direct impact costs. Such costs derive from the sheer number and scope of changes to the contract. The result is an unanticipated loss of efficiency and productivity, in turn increasing the contractor's performance costs and usually extending his stay on the job.

DILUTION OF SUPERVISION

occurs when supervision must be diverted to analyze and plan change, stop and re-plan affected work, take off, order and expedite material and equipment, incorporate change into the schedule, instruct foremen and journeymen, supervise work in progress, and revise punch lists, testing, and start-up requirements.

LOSS OF EFFICIENCY

or Percent Lost Efficiency is the loss of productive manhours taken as a percent of the total manhours worked. The loss of efficiency can be a result of many different factors such as overtime, overmanning, etc.

LOSS OF LEARNING

is a reduction in the speed at which a task can be performed. Because a worker (in any trade, not just in construction) repeatedly does a certain task such as hammering a nail or installing wire, he gets better and faster at performing that task the more he repeats it. Having an abundance of change orders prevents this repetitive learning and, consequently, reduces the overall efficiency of labor on the entire project.

MAN-HOUR

is a time unit equal to one hour of work performed by one worker.

MANPOWER LOADING CURVE

is a curve displaying the relationship between the number of workers on a project and time. Typically, the y-axis displays the manpower level (or the number of workers onsite) and the x-axis displays the unit of time, often in terms of weeks or months depending on the overall length of the project.

NET WORKING AREA

is used in determining the impact of stacking of trades. The Net Working Area is the total floor space minus any unusable portions, such as a production line, elevator shaft, or permanent fixtures.

OUT-OF-SEQUENCE WORK
results from a request for change that interferes with the planned flow and sequencing of the project. The interference results from mobilization and demobilization, loss of learning, loss of momentum, etc.

OVERMANNING
happens by increasing the number of labor crews above optimum. The optimal number of labor crews is the minimum number of workers required to perform the task within the allocated timeframe. Alternatively, overmanning can be defined as an increase in the peak number of workers of the same trade over and above the planned or estimated peak.

OVERTIME
is the work performed over and above 8 hours per day and 40 hours per week. Overtime can occur in a variety of schedules, including 5 days of 10 hours worked per day (5-10's), 7-8's, 6-10's, 7-10's, etc.

OWNER FURNISHED ITEMs
include both material and equipment bought and supplied to the specialty contractor by the owner or, possibly, the general contractor.

PERCENT CHANGE
shows the percentage of change experienced on a project in relation to the Original Budgeted Workhours. Percent Change is calculated by dividing the total change order hours by the Original Budgeted Workhours, and then multiplying by 100 to convert the result into a percent.

PIECEMEAL WORK
arises when only small portions of separate tasks are done instead of completing a work task from start to finish. When this happens, there is no rhythm or flow to the work. This, in turn, slows the workers. Piecemeal work is also related to the reassignment of manpower and the loss of learning.

PROCESSING TIME
is the period of time between initiation of a change order and the owner's approval of the change order.

PRODUCTIVITY
is the ratio between input and output. Input can include all resources such as labor, materials, equipment, and money. Alternatively, productivity can be defined in terms of man-hours per unit of work.

REASSIGNMENT OF MANPOWER
occurs when management must move-on and move-off workers because of unexpected changes, excessive changes, or demands made to expedite or reschedule completion of certain work phases.

SCHEDULE ACCELERATION
is an increase in the speed of development or progress from the normal experienced time or optimal time for the type and size project being planned within a given set of circumstances.

SHIFT WORK
refers to the hours worked by a second group of craftsmen whose work on a project is performed after the first, or primary, workforce of the same trade has retired for the day. A second shift experiences no significant overlap of hours in which its craftsmen are working in conjunction with members of the first shift.

STACKING OF TRADES
(also commonly know as overcrowding) considers the total number of craftsmen from all trades working in a given area.

TURNOVER
is the ratio of the number of craftsmen hired to replace those who have left to the number of craftsman initially.

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PART 2: BEST PRACTICES TO REDUCE THE IMPACT OF PRODUCTIVITY FACTORS FOR ELECTRICAL CONTRACTORS

INTRODUCTION

The purpose of this document is to provide project managers, company executives and the electrical construction industry with a proactive tool to reduce the negative impact of the productivity factors identified in Factors Affecting Labor Productivity for Electrical Contractors, previously published by this author and ELECTRI international. That document provided definitions and numerical thresholds for impact of each productivity factor. The same definitions and values remain applicable herein. This document will provide a series of best practices that can be used by project managers to reduce the negative impact of productivity factors. **Each best practice will be formatted as follows:**

- ***1.*** *Introduction and expanded definition*
- ***2.*** *Guiding Principles*
- ***3.*** *Conditions for Successful Application*
- ***4.*** *Results*

This document presents a collection of ten best practices that can be employed in situations involving potential productivity loss. In reviewing these best practices, it must be understood that, while this document is intended to be as widely applicable as possible, it is not tailored to fit the specific needs of every project. Regardless of the methods used on their specific projects, this author recommends that project managers understand the best practices presented here, as they are also applicable as management best practices.

LIST OF AND BRIEF DEFINITIONS OF BEST PRACTICES

1. Enhancing Coordination Between Project Parties

Effective coordination between electrical contractors and other project parties is essential for minimizing the loss of productivity and achieving project success. Given the complexity level of electrical construction, project managers and team leaders must understand that effective coordination and project alignment do not just happen. Instead, they require discipline to be achieved and maintained.

2. Increasing Construction Involvement in Design

The effective and timely integration of electrical construction-specific knowledge and experience into a project's design can help achieve overall project objectives in the best possible time and can ensure accuracy and efficiency at the most cost-effective levels.

3. Minimizing Negative Impacts of Schedule Compression

Electrical construction frequently encounters situations that demand schedule compression, because of the trade being last in line to perform work. Traditionally, the most common methods to compress the construction schedule are overtime (working more hours), overmanning (adding additional workers), or a second shift (adding a second crew that takes over at the end of the first shift). These practices have some negative impact on labor productivity, but the precise level of that impact varies.

4. Reducing Absenteeism and Turnover

A stable workforce is essential to maximizing onsite productivity. Frequent turnover of workers can result in lost time due to re-training and integrating the new people into the existing crew, while absenteeism reduces the amount of hands available onsite. While both absenteeism and turnover have adverse impacts on project performance, contractors must sometimes accept that a low level (2-3%) of absenteeism and turnover is a natural part of the industry. Still, production can suffer when even one worker is absent for one day, meaning that minimizing these factors is crucial.

5. Minimizing and Integrating Changes

The electrical construction industry understands that frequent and untimely changes into a project can lead to problems and hinder project success. Changes interrupt the flow of work, decrease labor productivity, create delays, cause schedules to slip, and inflate costs which in turn may generate claims and possibly costly litigation. However, in some cases, project teams sometimes face inevitable changes. For optimal project performance, the project team should anticipate such changes and efficiently integrate them into the normal flow of work.

6. Schedule Updating and Look-Ahead Planning

Applying regular schedule updating and short interval controls is essential for project success, as it helps maintain a productive work pace throughout the project. Also, these two practices are of critical importance as they enable accurate forecasting of the remaining work, thus revealing if corrective measures must be taken to meet project goals.

7. Managing the RFI Process

A project with significantly more Request for Information forms (RFIs) is undesirable, because crews lose productivity while waiting for information, especially when it takes weeks for other project parties to respond. Often, these crews demobilize and remobilize more than once, adding costs to the project. Additionally, crew morale and learning curve effects are significantly reduced under these circumstances. Therefore, the number of RFI's and their processing time can be a major source of waste for projects.

8. Reacting to Out of Sequence (OOS) Work

Out-of-sequence work (OOS) refers to work that is not performed in a logical, planned way. It is very common in construction projects, and can have serious negative impacts on project performance. Reacting to OOS in the right manner is one of the most important things that the project team should always be ready to do.

9. Increasing Owner's Participation During Construction

The effective and timely participation of owners during construction is essential for achieving the overall project objectives in the best possible time and accuracy at the most cost-effective levels.

10. Increasing Engineering Support to Construction

The effective and timely support of engineering during construction is vital for successful project execution.

11. Improving Vendor Performance by Establishing a Vendor Management System

The use of a Vendor Management System can reduce delay in materials and can improve overall material quality and cost.

The table below shows which of the 11 recommended best practices are applicable to various productivity factors.

Table 1.1: Applicability of Best Practices to Productivity Factors

PRODUCTIVITY FACTOR	Enhancing Coordination Between Project Parties	Increasing Construction Involvement in Design	Minimizing Negative Impacts of Schedule Compression	Reducing Absenteeism and Turnover	Minimizing and Integrating Changes	Schedule Updating and Look Ahead Planning	Managing the RFI Process	Reacting to Out-Of-Sequence (OOS) Work	Increasing Owner's Participation during Construction	Increasing Engineering Support During Construction	Improving Vendor Performance by establishing a Vendor Management System
Cumulative Impact	●	●		●	●		●		●	●	
Overmanning			●		●	●				●	●
Overtime			●		●	●				●	●
Second Shift			●		●	●				●	●
Stacking of Trades	●		●		●	●		●		●	
Out of Sequence Work	●		●		●	●		●		●	●
Weather			●			●		●			
Owner-Furnished Items	●		●			●			●		●
Access Constraints	●		●			●			●		
Beneficial Occupancy	●		●			●			●		●
Loss of Learning	●			●				●			
Change Order Processing Time	●	●					●			●	
Absenteeism			●	●		●					
Turnover			●	●		●					
Dilution of Supervision	●		●				●				
% Design Complete	●	●							●	●	
AE Coordination	●	●							●	●	
AE Support	●	●							●	●	
Manpower Shortage			●	●		●					●

EXPANDED DEFINITIONS OF BEST PRACTICES

ENHANCING COORDINATION BETWEEN PROJECT PARTIES

INTRODUCTION

Coordination between project parties is typically maintained through pre-onstruction planning meetings, kickoff meetings, and regularly scheduled weekly or biweekly meetings. It is important that the electrical contractor takes a leadership role in these meetings to detail what work needs to start, what work will be completed, and what work will still be in progress at the time of the next meeting. A role and responsibility matrix should be well-defined and frequently referenced, and the reliability of promises should be tracked. **The following are some methods that may be used to increase coordination:**

GUIDING PRINCIPLES

1. ***Alignment Procedure: Having well-formulated procedures is a key driver of effective coordination. Such procedure should include provisions regarding:***
    a. *Team building and team alignment.*
    b. *On-boarding of team members and stakeholders.*
    c. *Cultural differences and constraints in the team make-up.*
    d. *Continuity of resources.*

2. ***Effective Supplier Integration: Effective coordination between contractors and suppliers is essential to ensure proper delivery of the equipment, material, and services required for successful execution. Effective coordination can be achieved through the following:***
    a. *Involving suppliers in project planning.*
    b. *Comprehensively incorporating supplier data requirements in RFQs and POs.*
    c. *Providing suppliers with proper understanding of project schedules, costs, contractual requirements, and commitments to quality.*
    d. *Involving suppliers in design and procedure reviews.*
    e. *Clarifying suppliers' scopes of work.*
    f. *Setting common project goals and team rules.*

3. ***The electrical contractor should ensure that they understand the long- and short-term goals of the project, and that their specific goals are in alignment with the project. Optimally, these goals should be designed in a way that all project parties are motivated to achieve them. This can be done through "alignment of interests," where all related parties tend to benefit from achieving the set goals.***
    a. *The project team should clearly communicate these goals along with the team rules. These rules should include communication protocols, and transparency.*

4. ***Monitoring and tracking progress and performance towards project goals.***
    a. *One way to monitor coordination between project parties is tracking the Percent of Promises Complete (PPC).*

5. ***Participate in planning of work among different trades and revealing any contradictions early on.***

CONDITIONS FOR SUCCESSFUL APPLICATION

1. ***Strong leader who supports alignment, one mission, mutual goals, buy-in, and consistent program of team building, as well as removing obstacles***

2. ***Contractual terms must be unambiguous.***

3. ***Compliance with contractual aspects is a must.***

4. ***CAUTION: Unaligned team members can negatively affect the alignment process.***

RESULTS

1. ***Creating a more comprehensive and effective problem solving culture instead of just having a problem identification culture.***

2. ***Increasing the speed of action/responses due to the team's cohesiveness.***

3. ***Improving the efficiency of processing changes, and integrating them in the normal flow of work.***

INCREASING CONSTRUCTION INVOLVEMENT IN DESIGN

The effective and timely integration of construction knowledge and experience into a project's design can help achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels. Electrical contractors should review contract documents as early as possible to identify design errors and omissions or coordination issues. They must also notify owners and design engineers to resolve these issues as far in advance as possible. Scheduling meetings with owners/design engineers in the early stages of the project is highly recommended. Following is a guide of how to effectively increase construction involvement in design.

GUIDING PRINCIPLES

1. ***Constructability involves thinking about how to build a project and determining what materials, methods, and techniques are best suited to its execution.***
    a. *Three constructability issues that have the greatest impact during the pre-construction planning phase of a project are the project plan, the site plan, and major construction methods.*
    b. *The constructability process at the project-level consists of three critical milestones:*
        - *Obtain constructability proposals,*
        - *Plan constructability implementation, and receive approval for the proposed changes to constructability*
        - *Implement constructability.*

2. ***Review the project's 3D model, and verify that all the needed information is present in the model.***

CONDITIONS FOR SUCCESSFUL APPLICATION

1. *The Construction personnel executing the project should be the ones participating in pre-planning (when and as needed).*
2. *Institute effective material management, document control, and project control systems.*
3. *Use compatible design systems.*
4. *Make design details available.*
5. *Ensure owner/GC support for the process.*
6. *Identify champions for the process and train staff to become knowledgeable.*

RESULTS

1. *Improved overall project predictability for cost and schedule*
2. *Higher labor productivity*
3. *Efficient turnover and startup*
4. *Improved safety and quality performance*
5. *Enhanced workforce morale*

MINIMIZING NEGATIVE IMPACTS OF SCHEDULE COMPRESSION

Electrical contractors are frequently confronted with the need to compress construction schedules. The three traditional methods to compress construction schedules are overtime, overmanning, and using a second-shift. These practices typically reduce labor productivity, but to different extents. Following is a brief guide of how to minimize the negative impacts of these practices, followed by a recommendation of the most favored practice in terms of having the least negative impacts among the three practices.

OVERTIME

Overtime consists of employing the existing crew members beyond the standard 40 hours per week. This typically includes the extension of the 8-hour day to a 9- to 12-hour day, the extension of the 5-day work week to a 6- or 7-day work week, or a combination of both.

GUIDING PRINCIPLES

1. *Overtime should be used in cases where schedule compression is a must, second-shift cannot be applied, and construction workers are not available for crew size increases, however Overmanning should be avoided at all costs.*

2. *Overtime can be effective in short interval schedule compression (4-6 weeks maximum).*

3. *Advanced planning including advanced tooling and planning of material layout and storage areas can reduce the negative impacts of overtime.*

CONDITIONS FOR SUCCESSFUL APPLICATION

1. *Provide employees extended weekend breaks on occasion to "recharge" crew productivity, especially during long durations of overtime.*

2. *Avoid employee burnout. It is recommended that, if overtime must be prolonged, a break equal to the number of overtime weeks be provided.*

3. *Rotate crews periodically to ensure that overtime is evenly distributed among the members.*

4. *Guard against some crew members who will purposely reduce productivity to maximize overtime income.*

5. *Paying at 1 1/2 times the normal hourly rate plus other union requirements can make the effective hourly labor rates double.*

6. *In most cases, two premiums are paid for scheduled overtime. The first is increased wages and the second is less productivity per man-hour worked.*

OVERMANNING

Overmanning involves the addition of workers to existing crews. For example, a 5-person crew may be increased to a 6-, 7-, or more, person crew. Research has shown that overmanning is the most detrimental to labor productivity and should be avoided as much as possible.

GUIDING PRINCIPLES

1. *Requires the availability of additional qualified construction workers.*

2. *Requires an increased awareness of safety issues and increased availability of accessible water, eating areas, people lifts, first aid stations, restrooms, etc. to accommodate the additional workers.*

3. *Requires additional supervision to maintain ratio of supervisors to workers.*

4. *Equipment and material delivery must be able to meet the needs of the additional manpower.*

5. *Have an ample work area without congestion (approximately 250 sq. ft. per worker).*

6. *It is recommended to assign the extra personnel to non-critical project tasks. Meanwhile, normal crew levels and assignments should be maintained for critical path items.*

7. *Overmanning is not recommended if equipment delivery requirements are critical.*

CONDITIONS FOR SUCCESSFUL APPLICATION

1. *This concept can be used to maintain 40 hour weeks and avoid overtime premium pay.*

2. *Lost productivity due to learning curve applications, training, orientations, start-up, and socialization must be evaluated.*

3. *Labor productivity tends to decrease as the percent overmanned increases.*

4. *Overmanning results in additional costs for tools, equipment, and increased supervision.*

5. *The administrative and labor costs associated with training new workers, orientations on project procedures and safety policies, and getting to know the new crew members must be considered.*

6. *Overmanning can result in stacking of trades.*

SECOND SHIFT

This practice involves using a second crew on a project, so each crew generally works an 8-hour shift. The second shift takes over following the conclusion of the first shift's work for the day.

GUIDING PRINCIPLES

1. *Requires supervision overlap for continuity between shifts.*

2. *Requires additional tools and separate gang boxes for each crew.*

3. *Requires the availability of qualified construction workers to form a second crew.*

4. *Requires the owner/GC to be willing to allow two crews and extended hours on the project.*

5. *Requires having easy access to project information so that decisions can be made when project management is not on-site.*

6. *Must keep first and second shift material deliveries separate.*

7. *Materials should be delivered earlier and more often and may require additional storage space.*

8. *To avoid rework, crews must complete 100% of the task prior to turning the work over to a second crew.*

9. *It is a best practice to assign the second shift crew a different area of the site and separate tasks and materials to avoid overlap and confusion.*

CONDITIONS FOR SUCCESSFUL APPLICATION

1. *Start up and learning curve issues reduce the initial productivity of each crew.*
2. *Continuity of work is lost, leading to productivity decreases.*
3. *A considerable body of literature suggests that shiftwork in general, and second shift work in particular, may have adverse consequences for the health and well-being of the worker.*
4. *If specialized tasks are required, training time must be included in the schedule and cost.*
5. *Second shifts result in additional costs for tools, equipment, and increased supervision.*
6. *The administrative and labor costs associated with training new workers, orientations on project procedures and safety policies, and getting to know the new crew members must be considered.*
7. *Well managed second shifts can yield negligible losses in labor productivity, given that crews/shifts tend to become equally productive in the long run.*
8. *This approach can be used to avoid the expense of premium pay for overtime*
9. *Although the crews are not working overtime, office support staff, material delivery staff, and management will be required to work additional hours to keep up with the needs of the crews.*
10. *Effective when rented or high cost equipment is necessary for production.*
11. *Effective for longer duration schedule compressions but not effective on very short durations.*
12. *Desirable when the work area is extremely congested during normal hours.*
13. *Effective when separate work tasks are available for each crew.*
14. *Successful when material requirements are minimal and available for both shifts.*
15. *Challenging to apply in very small projects.*
16. *May not be desirable if security of the project is a problem.*
17. *May not be appropriate if tedious control is required to maintain the project (e.g. airports, prisons, etc.).*

REDUCING ABSENTEEISM AND TURNOVER

Construction projects need a stable and productive workforce. While absenteeism and turnover have adverse impacts on project performance, contractors sometimes deal with such problems as being a natural part of the job. Still, production can suffer when even one worker is absent for one day. Following is a guide for reducing absenteeism and turnover.

GUIDING PRINCIPLES

1. ***Monitor absenteeism, and record attendance.***

2. ***Humanize the project (enhance the worker's quality of life on the project site).***
   - *a. Make sure workers are satisfied with the provided restrooms, eating areas, etc.*
   - *b. Solicit craft input on their priorities.*

3. ***Establish a safe worksite and make sure that the project is perceived as safe by the workers themselves.***

4. ***Understand the workforce, their motivators, and the competing projects (use labor surveys).***
   - *a. Create and apply an effective incentive programs.*
   - *b. If the project is union, engage early with Business Agents (BAs).*
   - *c. Optimize the use of planned overtime.*

5. ***Provide beneficial training for workers.***
   - *a. The Business Roundtable (BRT) concluded that each dollar invested in craft training can yield $1.30 to $3.00 in benefits. These benefits include reducing absenteeism and turnover rates by approximately 15% each.*

6. ***Interact with workers during job-walks.***

7. ***Create a social atmosphere on the jobsite and within the company to increase retention of workers***

CONDITIONS FOR SUCCESSFUL APPLICATION

1. ***Be receptive to craft feedback.***

2. ***Implement a continuous program.***

3. ***Avoid overly optimistic planning related to labor availability***

4. ***CAUTION: Demonstrating no action after asking workers for their feedback will weaken credibility.***

5. ***Be prepared for additional costs for the following:***
   - *a. humanizing the project site*
   - *b. providing workers with beneficial training*
   - *c. developing and administering labor survey*
   - *d. applied incentives (such as implementing overtime)*

RESULTS

1. *Increasing labor morale*
2. *Creating a positive culture for the project*
3. *Reducing multiple training costs for new workers*
4. *Improving productivity, due to the learning curve effect.*

MINIMIZING AND INTEGRATING CHANGES

Owners, designers, and construction contractors are all aware that introducing untimely changes into a project can lead to problems and hinder project success. Changes interrupt the flow of work, decrease labor productivity, create delays, cause schedules to slip, and inflate costs which in turn might generate claims and possibly even costly litigation.

However, in some cases, electrical contractors sometimes face inevitable changes. For optimal project performance, electrical contractors should anticipate such changes and efficiently integrate them into the normal flow of work. Following is a guide of ways to anticipate and integrate inevitable changes into the normal flow of work and how to minimize and integrate changes throughout the project lifecycle.

GUIDING PRINCIPLES

1. ***Avoid starting construction before having a reasonable definition of the scope of work.***
2. ***During pre-construction planning, the electrical contractor should highlight the elements that are prone to change early on so that they are prepared from the beginning.***
3. ***Commit early in the process to implementing constructability and communicate with the client.***
    a. *Try to make the inevitable changes as early as possible.*
    b. *Coordinate and communicate with other trades and the client*
4. ***Reduce task scope to manageable activities.***
    a. *Break down complex tasks or work assignments into smaller, well-defined, short duration subtasks in which schedule activities can be established for control.*
    b. *This allows the project team to remain flexible and able to react to anticipated changes.*
5. ***Provide input to ensure electrical activities are coordinated within the 3D model.***
    a. *The Project team should set "building an integrated model" into the common project goals.*
    b. *Use BIM or similar tools to identify clashes between different trades early on.*
6. ***Hold coordination meetings early and regularly with the contractors throughout the project to solve potential problems collectively and avoid possible changes.***
7. ***Track, report, and assess changes.***

8. ***The contractors should review plans and specifications.***
    a. *Match them to those used to prepare the estimate.*
    b. *Make sure that required material types are known and available, are able to be acquired, and are able to be substituted.*
    c. *Make sure that testing techniques and inspection processes are specified.*
    d. *Make sure that construction standards are specified.*
    e. *While reviewing plans and specifications, the electrical contractor should create a list of unknown information and prepare Request for Information forms (RFIs) to allow for adequate time for response from the engineer – in advance.*

9. ***Expedite change orders.***

10. ***Once the change is proposed, hold a coordination meeting about the change, its estimated impacts, and the plan of responding to the change. Make sure to communicate the results of this meeting to all related parties quickly and clearly.***
    a. *Contractors should refer to a publication by this author and ELECTRI International:* ***Factors Affecting Labor Productivity for Electrical Contractors***

CONDITIONS FOR SUCCESSFUL APPLICATION

1. ***Create an identifiable and agreed upon process for scope freeze and change management, including the approval process for changes, pricing principles, and the impact on cost and schedule.***

2. ***Have a clear strategy about integrating the approved changes into the normal work-flow.***

3. ***Evaluate changes with respect to project objectives.***

4. ***Identify changes early and arrive at expeditious resolution.***

5. ***Institute effective change management with disciplined work release/notice to proceed processes.***

6. ***Analyze necessary pricing changes associated with administration, staff, and impact.***

RESULTS

1. ***Time and cost savings (cost avoidance)***

2. ***Avoidance of potential disagreements between project parties.***

SCHEDULE UPDATING AND LOOK-AHEAD PLANNING

To maintain a productive work pace throughout the project and to ensure project success, the schedule should be regularly updated. One such method is to use short interval controls, which is the practice of defining objectives in 2-3 week intervals to allow the schedule to react to project conditions. Also, schedule updating and look-ahead planning are critically important as they enable presenting a realistic forecast of the remaining work, thus revealing if corrective measures must be taken to meet project goals. The following is a guide of how to implement proper schedule updating and short interval controls.

GUIDING PRINCIPLES

1. ***Make sure that project foremen, superintendents and control managers have experience with the project type and size, so they can achieve realistic plans.***

2. ***Conduct daily huddles (pre-task planning)***
    a. *Daily huddles are short meetings that should be held every day before starting the field work. In these huddles, each participant should clearly respond to the following questions:*
        - What did I accomplish yesterday, and did it further project goals? – The answer should be measurable.
        - What will I do today? – The answer should be measurable.
        - Where on the site will I work today? – The answer should be specific.
        - Who will I work with today? – The answer should be specific.
        - How will I accomplish my work today? – The answer should be specific.
        - What obstacles are impeding my progress? – The answer should be specific.

3. ***Weekly all-foreman coordination meeting.***
    a. *Hold an informal meeting of all project foremen to address overlapping activities and identify potential problems regarding the following week's work activities.*
    b. *Make sure to resolve conflicts in the field at the front-line supervision level.*

4. ***Perform 4-week rolling schedule review on weekly basis.***

5. ***Use a defined process for progress tracking and assessment to measure progress against planned work.***
    a. *Use Earned Value Management (EVM), preferably using working-hour data to capture labor productivity.*
    b. *Publicly monitor Percent of Promises Complete (PPC) for each trade.*
    c. *Document and communicate reasons for not adhering to the latest updates or not being on track*

6. ***Document any delays or obstructions encountered, including out of sequence work, access constraints, stacking of trades, etc.***

CONDITIONS FOR SUCCESSFUL APPLICATION

1. ***Complete team involvement in the updates.***

2. ***Ensure all participants are using the same version of the master schedule.***

3. ***Feed design changes into the work process in a timely manner.***

4. ***Assign a strong leader who communicates well and gets all involved, and communicates the plan to all in weekly meetings***

5. ***Implement effective variance analysis.***

6. ***Establish realistic production goals and measure performance.***

7. ***Facilitate and ensure proper adherence to schedule priorities.***

8. ***Make sure that the produced reports have a consistent, easy-to-follow format.***

9. *CAUTION: Longer durations between schedule updates reduces the control of schedule progress and the management of staff productivity.*

10. *Insist on essential, accurate quantity reporting.*

11. *Pay attention to critical path as well as overall progress.*

12. *Keep meetings schedule updates precise and objective.*

13. *Be sensitive to how much you are tying up manpower resources (including supervision).*

14. *Be mindful that scheduling personnel and software costs may increase*

RESULTS

1. *Timely feedback.*

2. *Improved predictability.*

3. *Improved schedule adherence.*

4. *Early problem identification.*

5. *Facilitating orderly flow of work.*

6. *Identifying early warnings for and occurrence of project distress*

MANAGING THE RFI PROCESS

A project with significantly more Request for Information forms (RFIs) is undesirable because crews lose productivity while waiting for information, especially when it takes weeks for other project parties to respond. Often, these crews demobilize and remobilize more than once, thereby adding costs to the project. Additionally, both crew morale and learning curve effects significantly drop when such events happen. Therefore, the number of RFI's and their processing time can be a major source of waste for projects. Following is a guide of how to manage the RFI process.

GUIDING PRINCIPLES

1. *Have a defined RFI process in place.*
    a. *During the preconstruction planning process, electrical contractors should review the project plans and specifications, create a list of unknown information, and prepare as many RFIs as needed, to allow adequate time for a response from the engineer.*
    b. *For complicated projects, make sure to have a sufficient number of design engineers available to respond to design-related questions in a timely manner. As a rule of thumb, electrical contractors need one full time design engineer (or equivalent) for every $10 million of work to support field operations.*

2. ***Train the project staff sufficiently to write adequate RFIs in a way that helps minimize processing time.***
    a. *Follow an established RFI format.*
    b. *Be specific about the information needed and include explicit questions(s).*
    c. *Limit each RFI to one issue.*
    d. *Include context to the issue/question(s).*
    e. *Propose constructible solutions (and state cost and schedule impacts) in the RFI.*
    f. *Use a consistent RFI numbering process among all contractors and subcontractors involved with the project.*
    g. *Use email to distribute RFIs to every involved party.*

3. ***Enable the use of technology for workers on-site.***
    a. *For example, make sure workers on-site have access to iPads (or similar devices) that have the project's integrated information model, as well as relevant lessons learned.*
        • *Access to onsite technology ensures that the most updated plans and drawings are accessible to the workforce.*
    b. *In some cases, ensuring on-site model access with printing ability can boost productivity.*
    c. *Explore the use of RFI platform software that can further automate the process (including the tracking process) to enhance overall efficiency.*

CONDITIONS FOR SUCCESSFUL APPLICATION

1. ***Prioritize RFIs in terms of criticality.***
    a. *Urgent RFIs should be answered within 24 hours; near critical RFIs should be answered within 3 days; and normal RFIs should be answered within 7 days.*
    b. *To minimize urgent RFI turnaround impacts and in order to facilitate keeping construction crews "on the scaffold", work this concept with the Increasing Engineering Support during Construction concept.*

2. ***Ensure having objective incentives to write RFIs that benefit the overall project performance.***

3. ***In some situations, contract terms might pose barriers to writing proper RFIs, as contractors traditionally do not design.***

4. ***Plan for the cost for making technological devices available on-site (including costs of technology connectivity)***

RESULTS

1. ***Rapid turnaround on RFI responses will reduce inefficiency and costs associated with mobilization and demobilization at the work force.***

2. ***Other benefits include:***
    a. *Better flow of work because of the better flow of information.*
    b. *Improved productivity.*
    c. *Improved worker morale.*

REACTING TO OUT OF SEQUENCE (OOS) WORK

Recent research constructed by this author found that 15% of all project activities are performed out of sequence, resulting, on average, in a 33% increase in schedule and a 25% increase in cost. Out-of-sequence work (OOS) is very common on construction projects and can have serious negative impacts on project performance. Reacting to OOS in the right manner is one of the most important things the project team should always be ready to do. Following is a guide of how to react to OOS.

GUIDING PRINCIPLES

1. ***Assess/address the cumulative impacts/risks of the subject OOS in terms of affecting productivity, schedule, cost, safety, and quality.***

2. ***Communicate the subject OOS and make it visible for everyone.***

3. ***Propose solutions to sequence the subject OOS back into the work process.***
    a. Do not stop current work and completely refocus unless absolutely necessary.
    b. Preserve the in-sequence work as much as possible.

4. ***Analyze the consequences of each proposed solution and select the most effective one that has minimum effects on productivity, schedule, cost, safety, and quality.***

5. ***Have an internal project team restart meeting to ensure team alignment on the reactive actions for the subject OOS.***

6. ***Investigate the root cause of the subject OOS (go back one step at a time till you reach the root cause). For example, apply the "5 whys" rule until you reach the root cause.***

7. ***When you know the root cause, take actions to prevent it from happening again.***

CONDITIONS FOR SUCCESSFUL APPLICATION

1. ***Communicate root causes and secondary causes of OOS.***

2. ***Have an aligned team***

3. ***Assign a Team Leader with authority to manage change.***

4. ***Keep accurate records.***

5. ***Schedule regular updates.***

6. ***Establish protocols for clear communications.***

7. ***Have a resource-loaded schedule***

8. ***Identify all critical milestones in the schedule.***

9. ***Openly communicate the recovery plan with assigned responsibilities.***

CONDITIONS FOR SUCCESSFUL APPLICATION

10. *Identify probable future OOS tasks and have plans to address them (proactive use of look-ahead scheduling).*

11. *For future activities, ensure having all predecessor activities in place before putting people to work.*

RESULTS

1. *Mitigate the impacts of OOS.*

2. *Determine the recovery plan.*

3. *Potential to save 25% of project costs and prevent schedule slip by up to 33%.*

INCREASING OWNER'S PARTICIPATION DURING CONSTRUCTION

Generally, electrical contractors have an obfuscated level of access to the owner, as they contract through a General Contractor (GC). However, with concerted effort, a relationship can be developed between the electrical contractor and the owner. The effective and timely participation of owners during construction is essential for achieving the overall project objectives in the best possible time and with accuracy at the most cost-effective levels. Following is a guide of effective ways to increase the owner's participation during construction.

GUIDING PRINCIPLES

1. *Have the owner be a part of the execution team.*

2. *Educate the owner about the different alternatives in terms of constructability and impacts on schedule and cost.*

3. *Be effective in communicating with the owner (understanding their limitations, time schedule, and reporting techniques).*

4. *Show the owners the positive impacts of their participation.*

5. *Be prepared to handle unforeseen market conditions that may impact material prices or availability thereby increasing the original contract amount.*

6. *Focus on scope adherence.*

CONDITIONS FOR SUCCESSFUL APPLICATION

1. *The owner should be dedicated to and accountable for the project's success.*

2. *The owner should limit owner-initiated scope changes that increase the project duration.*

3. ***The involved owner representative should have the proper qualifications and understanding to be involved.***

4. ***Establish proper roles and responsibilities (Ex. The owner should not direct craft during construction execution, unless doing so is part of the plan).***

5. ***Owners and contractors should consider themselves as members of the same team. They both should have the attitude of "his gain is my gain, and his loss is my loss."***

6. ***The contract must have clear provisions listing the owner's obligations and decision- making rights. If this is not articulated in the contract itself, a memorandum of understanding should be formulated during the kickoff meeting to define owner's roles and responsibilities.***

7. ***Owner's involvement during construction is less in effective in green field and more effective in brown field.***

8. ***Owners can sometimes be over-involved if micro-managing. This will have a counterproductive effect.***

9. ***If done wrong, an owner's heavy involvement during construction might lead to scope creep.***

10. ***Anticipate some increased expenses for the owner.***

RESULTS

1. ***When the owner is well educated by the contractor and engineer about the different project parameters impacting construction, his/her involvement will be constructive.***

2. ***By having the owner constructively involved during construction, mutual decisions will be made efficiently, minimizing productivity loss.***
    a. Other benefits of minimizing change include positive cost implications due to fast turnaround decisions.

INCREASING ENGINEERING SUPPORT TO CONSTRUCTION

The effective and timely support of engineering during construction is vital for successful project execution. Following is a guide of effective ways to increase engineering support during construction.

GUIDING PRINCIPLES

Have a staffing plan and a communication plan (process and procedure) to ensure engineering support to construction.

1. ***Rapid response in supporting decision making.***
    a. Engineers in the field providing real-time approval/authorization.
    b. Expedited RFI processing.

2. ***Have the right people with proper authority to support construction.***

3. ***Allow easy and quick means for the contractor to communicate with the engineer.***

CONDITIONS FOR SUCCESSFUL APPLICATION

1. *Adequate field engineering staff.*
2. *Adequate engineering support in the project execution plan.*
3. *Communicate the number of required engineering personnel needed per volume of work.*
4. *Some project delivery systems (e.g. IPD) allow contractually for more engineering and owner support.*
5. *Use the contract to address this need upfront.*
6. *Avoid a claim-oriented culture.*
7. *Budget for it upfront – while some increase in cost will occur, it will pay for itself over time.*

RESULTS

1. *Generally, as the engineering support during construction increases, the OOS activities, frequency, mitigation cost, and mitigation hours, decrease.*
2. *Removing unnecessary obstacles.*

IMPROVING VENDOR PERFORMANCE BY ESTABLISHING A VENDOR MANAGEMENT SYSTEM

This concept involves the development of a vendor management system. This requires working with project vendors on both an informal and formal basis to increase their commitment to optimal performance on the project. Vendor commitment can be measured as: their on-time delivery record (closer to 100% is better), quality of materials, minimization of financing and transportation costs, and reasonable overall cost. Vendors can also provide valuable logistical support with material handling, transport, delivery, and collection of surplus materials.

GUIDING PRINCIPLES

1. *Vendor performance can be improved by including vendors in project pre-planning and planning meetings as well as in partnering agreements.*
2. *Relationships with vendors must be established before the project begins. Once the relationship is established, it will carry from project to project, and only new vendors will require this additional management effort.*

CONDITIONS FOR SUCCESSFUL APPLICATION

1. *Management must be committed to working with the vendors to improve performance.*
2. *Once a successful relationship is established with a*

3. *The commitment to the vendor must be made clear before the contractor can expect that the vendor will meet the goals of the vendor management system.*

4. *Selecting a vendor based on a low bid without establishing a relationship or its performance record can lead to cost increases with late deliveries and poor quality.*

5. *Breaking a relationship established with a vendor without just cause can lead to unfavorable vendor performance in the future.*

6. *To maximize communication and facilitate rapid response to project needs, it may be prudent to set up a vendor workspace or office within the contractor's office. This applies the 'Big Room' concept – a tenet of lean construction.*

RESULTS

1. *A vendor management program can reduce the number of expediting and/or purchasing personnel required, reducing labor overhead.*

2. *Additional costs will be incurred to cover the additional scope of the vendor's performance. However, these costs may be recouped in savings on skilled labor required to move materials.*

3. *Material costs with established vendors may be slightly more. However, this cost will be greatly outweighed by the cost savings derived from on-time deliveries, quality materials, reduced uncertainty, and tighter bidding margins.*

4. *The use of computer-generated spreadsheets listing all bid items for vendor quotations can reduce material costs. The spreadsheet provides a document that will allow the contractor to review each bid item to better control and red flag items that appear excessive or items that should be replaced with specified alternates.*

CONCLUSION

This document provides a comprehensive set of best practices to minimize the impact of different productivity impediments to project outcomes. While each practice targets a certain area of productivity impact, the reader should consider the entire document and select the best practice(s) suiting their situation.

For each practice, we have provided areas in which cost impact may exist or occur due to the implementation of said practice, conditions that will lead to a more successful application, and guiding principles to apply the best practice. Each practice is also thoroughly defined, in an effort to locate it in the context where it may be most effective.

The best methodology to apply the knowledge herein is a proactive one – effectively forecasting productivity impediments can allow for active minimization. However, this document can also be used after the fact to improve policy and practice for future projects by applying lessons learned from projects that struggled with productivity loss.

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3 PART 3: TO BID OR NOT TO BID?

FACTORS THAT AFFECT BID SUCCESS FOR ELECTRICAL CONTRACTORS

INTRODUCTION

The most common means for electrical contractors to procure work is through competitive bidding. In general, most public agencies, such as state or federal governments, rely heavily on competitive bidding to acquire and award work to contractors. Electrical contractors typically contract with General Contractors/Construction Managers as a subcontractor or they may contract directly with the state as a separate prime contractor. In addition, electrical contractors can bid for work under the traditional sequential delivery system for which, typically, the design is complete at the time of bid.

The other model of bidding is the 'fast-track' model, with design and construction overlapping, as in the case of Design-Build, and Construction Management As Agent/At Risk. Fast-Track delivery causes a substantial risk for the electrical contractor, as design document(s) is/are dynamic, rather than static, and there is always a difference between bidding document(s) and construction document(s). In the experience of this researcher, Fast-Track model design documents are released between 70% and 80% complete.

Since the majority of the research referenced herein is this researcher's own work, this document will not have inline citations. A full list of references is provided in Appendix 1.

BID HIT-RATE AND COMPANY GROWTH

Research conducted by this author found the national average for a hit-rate is eight percent, i.e., contractors will win eight percent of the projects on which they bid. Estimating is an expensive process, and contractors need to be selective when they bid for work. The cost of estimates ranges between 0.25% and 0.5% of the project cost, depending on the complexity. Typically, electrical contractors have some sort of internal process, formal or informal, for evaluating their chances of winning a bid. In most cases, the contractors' estimates should be very close when they evaluate the direct cost components of labor, materials, or equipment.

However, the difference between two estimates will largely depend on a contractor's evaluation of risk or contingency. Contractors typically add a small percentage to their markup in terms of contingency to account for risk. On the other hand, they add higher percentages of contingency to their markup to allow for risky jobs. This current system is rather informal and based largely on intuition. This research endeavors to provide a quantitative assessment of bidding factors, with the goal of allowing electrical contractors to improve their hit-rate.

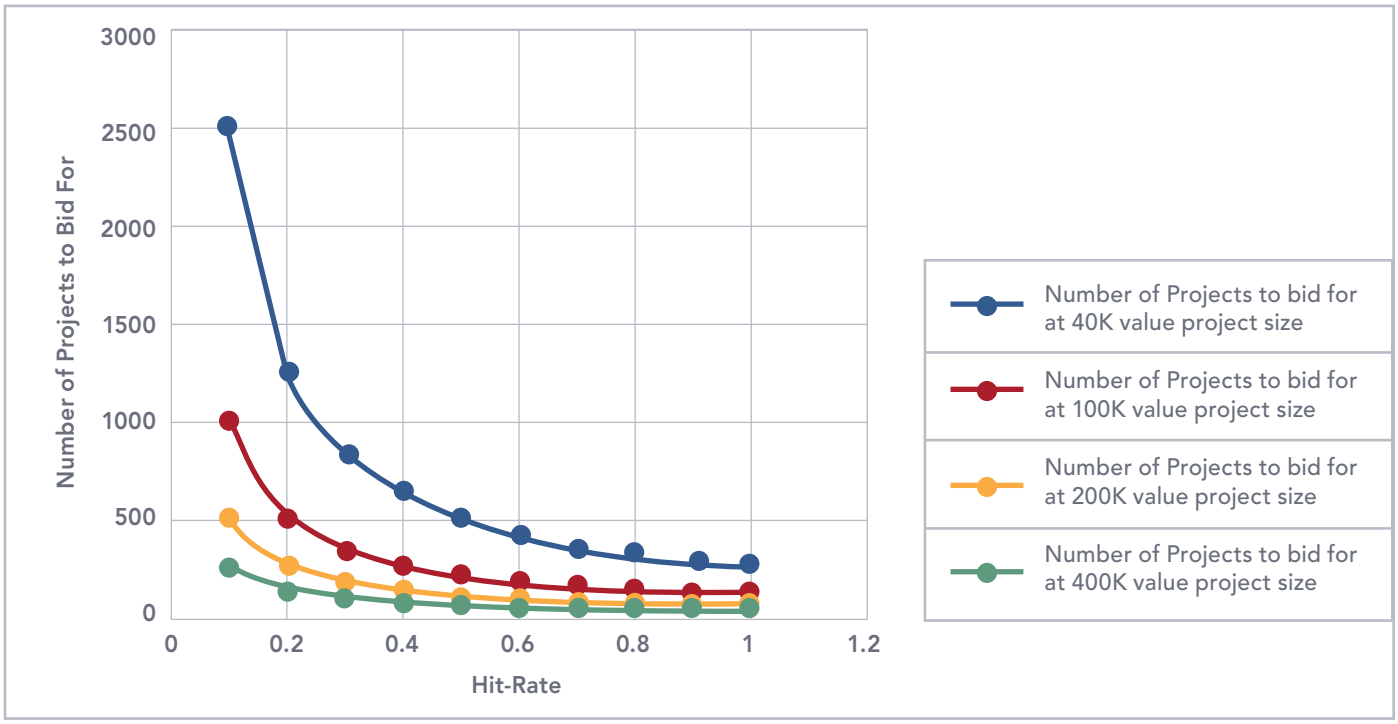
For electrical contractors to grow at a healthy rate, with a minimum number of projects on which to bid, they must achieve a hit-rate of thirty percent. In order to improve their hit-rate, contractors should establish evaluation criteria and analyze both successful and unsuccessful bids. Table 1 below presents a hypothetical contractor with annual sales or annual sale increase of $10 million, assuming an average project size of $40,000. A hit-rate of less than thirty percent dramatically increases the number of projects a contractor must bid in order to achieve the desired percentage of growth or dollar value of sales.

Table 1: Hit Rate vs Number of Projects to Bid at Specific Values

HIT-RATE	PROJECTS TO BID FOR AT 40K VALUE	PROJECTS TO BID FOR AT 100K VALUE	PROJECTS TO BID FOR AT 200K VALUE	PROJECTS TO BID FOR AT 400K VALUE
0.1	2500	1000	500	250
0.2	1250	500	250	125
0.3	833.33	333.33	166.66	83.33
0.4	625	250	125	62.5
0.5	500	200	100	50
0.6	416.66	166.66	83.33	41.66
0.7	357.14	142.85	71.42	35.71
0.8	312.5	125	62.5	31.25
0.9	277.77	111.11	55.55	27.77
1	250	100	50	25

The size of the projects in question has a substantial impact on the total number of projects required to bid on, and the potential for lost annual sales. Figure 1, on the following page, shows the relationship between bid hit-rate and the number of projects required to bid on when the project size is $40K, $100K, $200K, and $400K. The figure demonstrates the dramatic decrease in the number of projects necessary to bid for to achieve a given sale value, as the hit-rate increases.

Figure 1: Decreasing Relationship Between Projects to Bid for and Hit-Rate



MODERN RISK FACTORS IN ELECTRICAL CONSTRUCTION

In the last 15 to 20 years, it was observed that several additional risk factors had emerged from adapting new delivery systems and misallocating risk through the use of one-sided contract language. **These modern risk factors can be summarized as follows:**

DECREASED QUALITY OF DESIGN DRAWINGS

At the time of contract, it is uncommon for a contractor to have a set of design documents that has been fully and properly coordinated with all other aspects of the project. As a result, there is often a need for immediate changes to resolve conflicts and interferences that should have been eliminated in the design phase. Additionally, many contract design documents are vague and/or ambiguous in their intent and contain errors and omissions that will affect the quality of work. One need only speak with a veteran project manager or craftsman to learn that the decreased quality of design documents negatively impacts the performance of construction.

INCREASED USE OF DISCLAIMER CLAUSES

Modern contract documents contain many disclaimer clauses that attempt to deny responsibility for the sufficiency and accuracy of the information contained in the project plans and specifications. Examples of disclaimer clauses include those that tell the contractor/subcontractor not to rely on the information contained in contract specifications; those that claim the drawings are not specific or detailed in nature; or clauses that instruct the contractor to oversee compliance with all local codes, regardless of what is shown in the documents.

SHORTENED CONSTRUCTION DURATION

Owners and developers have established the importance of shorter construction duration due to both cost and shorter time-to-market windows of positive cash flow. However, this has correspondingly increased the use of fast-track construction practices, and caused plans to be distributed much earlier than appropriate, thereby causing confusion and an inexactness in details presented. Moreover, the short duration can create an unrealistic schedule and force contractors to use schedule acceleration techniques such as stacking of trades, overmanning, or overtime in order to keep pace. The presence of these acceleration techniques further exacerbates the impact of any changes made.

INCREASED COMPETITION

As a result of the increase in competition for contracts, the current construction climate runs on extremely tight profit margins with an industry average of two to three percent. The number of contractors in the United States has risen meteorically in the last two decades, yet the amount of work available (in dollars) did not correspondingly increase. The current competitive environment precludes contractors from having adequate contingency to absorb costs arising from non-estimated conditions such as delay, inadequate design work, or excessive change orders. With no mode of impact dissolution, contractors are forced to dispute the project impact costs caused by owner actions through change orders or other disruptive activities.

ESTIMATING RISK

Quantity takeoff can impose a particular risk to estimators. **There are four principal components of quantity takeoff:**

COMPONENT 1:

Items that are listed. This component lists all major equipment (such as switch gears, transformers, control panels, bus duct and motor control centers) and is usually quoted by vendors.

COMPONENT 2:

Items that are counted. This component includes outlet boxes, devices, fixtures, and motor connections. ***Components 1 and 2 represent three fourths of the material cost in the estimate.***

COMPONENT 3:

Items that are measured. This component involves measuring conduit, wire, trays, cables, etc. This component accounts for at least fifty percent of the labor hours allocated for a particular project. Material cost for this component represents the remaining twenty five percent of material cost.

COMPONENT 4:

Items that are not defined in the bid document. In many cases, owners and engineers expect contractors to include items that are not shown on or included in the drawings, but are essential to offer a complete and operable system, or to meet the standards of the owner.

As a result of the above classification, estimators must pay careful attention to component 3, because of the high labor hours that may result from it, exposing contractors to financial distress. In general, risk and profit should be correlated. As a result, in the case of higher-than-usual-percentage of component 3, estimators must increase their Factor to reflect the high risk of labor component. On the other hand, projects that consist mainly of procurement of equipment (component 1) impose less risk, and thus the Factor may be lower.

The word Factor represents a dollar value added to the bid by the electrical contractor. It is a decision made by the contractor and used to fund perceived risks. In academic literature, the word Contingency is often used interchangeably with the word Factor. In this document, Contingency is defined as the dollar value a contractor is instructed to add to a bid price and can be used to fund owner/GC/CM issues.

In an effort to allow contractors to better evaluate the risks present in a project, this author has developed the following assessment, divided into nine parts, with each part focusing on a different area that may increase risk. Each question within that area is given a range. Respondents were asked to rate the impact of each question on a weighted numerical scale. The maximum possible value (most positive or negative impact) was +5/-5. Throughout this worksheet, any assumed risk on the part of the contractor equates to a minus rating on the applicable scale. Similarly, opportunity that is created equates to a positive rating on the applicable scale. It should be noted that the numerical scale provided herein is a demonstrative example. Different companies may have different needs, priorities, or constraints that would necessitate the creation of a new scale or the modification of this one.

SECTION 1: RELATIONSHIP WITH THE DESIGN ENGINEER(S)

- *Have we previously worked with this engineer? (Max Limit: +1/-1)*
- *Are the design documents (plans and specifications) complete? (+2/-2)*
- *Is the design free of readily apparent problems? (+3/-3)*
- *Is there a reasonable procedure for the administration of change orders? (+1/-1)*
- *Is there a reasonable procedure for the administration of punch-list items? (+1/-1)*
- *Is there a reasonable process for the administration/approval of shop drawings and submittals? (+1/-1)*

SECTION 2: RELATIONSHIP WITH THE OWNER/CONSTRUCTION MANAGER/GENERAL CONTRACTOR
(FROM PRIOR EXPERIENCE OR BY REPUTATION)

- *Does the GC/CM treat the bid in an ethical manner during the bidding process? (+2/-2)*
- *Does the GC/CM have a good reputation for the working relationship with electrical contractors (+2/-2)*
- *Does the GC/CM team have the ability to manage the scope of the project? (+3/-3)*
- *Does the GM/CM have a reputation or history of making progress payments on time? (+1/-1)*
- *Is additional work expected to be performed? (+1/-1)*
- *Does the GC/CM coordinate between trades effectively in the project? (+2/-2)*
- *Does the GC/CM have a realistic expectation of the scheduled time for the completion of the project? (+1/-1)*

SECTION 3: BID PREPARATION TIME FRAME

- *Does the language of the Bid Form require the assumption of major risk (such as change order clauses, no damage for delay, and/or different site conditions)? (+4/-4)*
- *Is the language of the bid clear about what is included/excluded in the scope of work? (+4/-4)*
- *Is the time allowed for bid preparation proportional to the complexity and size of the project? (+2/-2)*
- *Are sufficient estimating personnel available to complete bid preparation in the allocated time? (+1/-1)*
- *Does the bidding process create risk/opportunity (new market, new client, etc)? (+2/-2)*

SECTION 4: COMPETITION

- *Is the number of bidders on the bidders list an advantage or disadvantage? [Advantage equals a positive rating, disadvantage equals a minus rating] (+1/-1)*
- *Have we been successful in prior bidding encounters with the contractors on the bidders list? (+2/-2)*
- *After assessing the competition, do we feel that we have a reasonable chance of being awarded the contract? (+3/-3)*
- *Are the competitors for this project Union or Merit Shops? (+3/-3)*

SECTION 5: ASSESSED RISK FACTORS

- *Is this a bidding opportunity (a new market, a new partnership, a new area, etc)? (+2/-2)*
- *Are we familiar with this type of project? (+2/-2)*
- *Are we comfortable with this size of project? (+2/-2)*
- *Has this type of work been reasonably profitable in the past? (+4/-4)*
- *Do we have past cost data available from similar projects? (+3/-3)*
- *Is this 'our kind' of project? (+2/-2)*
- *Do unique construction methods create a risk/opportunity? (+4/-4)*
- *Does the project require hazardous work (e.g. asbestos, contaminated soil, etc.)? Is this a risk or an opportunity? (+4/-4)*
- *Does the completion date allow for a realistic schedule? (+4/-4)*
- *If the project requires complex phasing, is this a risk or an opportunity? (+2/-2)*
- *Does the project expose us to unusual safety risks? (+3/-3)*
- *Is the project of adequate size for us to be competitive? (+2/-2)*
- *Has the client set a realistic budget? (+3/-3)*
- *Do we need the project for our field personnel and/or management? (+4/-4)*
- *Is our level of available manpower sufficient to complete the project scope? (+3/-3)*

SECTION 6: GEOGRAPHICAL LOCATION

- *Is this a geographic area with which we are familiar and do we have relationships with all parties involved (i.e. city/state officials, business managers, and union leaders)? (+2/-2)*
- *Does the location create risk or opportunity? (+2/-2)*
- *Does the project location create risk in terms of distance, housing availability, or housing quality? (+1/-1)*
- *Are unusual transportation problems caused by the site location? (+1/-1)*
- *Does the labor market at the site create risk or opportunity? (+4/-4)*
- *Are partners available for joint-venture to complete the project scope? (+3/-3)*
- *Are there subcontractors in the area to whom we could subcontract work? (+3/-3)*
- *Are there restrictive union practices (such as mobility language or prefabrication) on the number of our own personnel we can use? (+2/-2)*
- *Are there other large projects competing for labor in the area? (+4/-4)*
- *Are there any unusual or nonstandard IBEW agreements, provisions, or practices in place in the project area? (+3/-3)*
- *Do anticipated/typical weather conditions during the project's scheduled timeframe create risk or opportunity? (+3/-3)*
- *Are we currently licensed to conduct business in the project area? (+1/-1)*

SECTION 7: PROJECT MANAGEMENT

- *Do we have adequate project management personnel available to staff the project if we are awarded the contract? (+5/-5)*
- *Do we have the type of equipment necessary for the project and is it available during the project time frame? (+1/-1)*
- *Is there a Project Labor Agreement (PLA) in place for this project? (+2/-2)*
- *Are project managers/field supervisors available to be involved in the bidding process? (+1/-1)*

SECTION 8: CONTRACTUAL OBLIGATIONS

- *Is the contract reasonable and fair to all concerned? (+4/-4)*
- *Will further contracts/amendments follow? (+2/-2)*
- *Is the specified length of warranty for the project reasonable? (+2/-2)*
- *Is the basis for payment acceptable? (+3/-3)*
- *Is the rate of retainage nonstandard or otherwise unusual? (+2/-2)*
- *Do liquidated damages/incentives create risk or opportunity? (+5/-5)*
- *Are there insurance/indemnification requirements that create risk? (+2/-2)*

SECTION 9: ANTICIPATED PRODUCTIVITY FACTORS

- *Is the work around an operating unit? (+3/-3)*
- *Is there adequate space to store, stage, and install materials on site? (+4/-4)*
- *Is overtime required? (+2/-2)*
- *Is shiftwork required? (+1/-1)*
- *Is the owner supplying materials (including bread-and-butter items such as conduit and wire)? (+4/-4)*
- *Is the owner supplying major equipment? (+1/-1)*
- *Are there anticipated access constraints to the site or project area? (+4/-4)*

Note: This is not an exhaustive list. For a more complete list of potential productivity factors, consult Factors Affecting Labor Productivity for Electrical Contractors: A Quantified Statistical Approach, also by Dr. Awad Hanna.

CONSIDERATION OF PRODUCTIVITY FACTORS

As stated previously, estimators need to evaluate some of the factors that may impact labor productivity when preparing a bid and adjust their bid accordingly. There are "known known" factors (that the estimator is aware must be considered), "known unknown" factors (that the estimator is aware he/she does not know), and "unknown unknown" factors (that the estimator is not aware of at all). Known known factors should be included in the estimate, while known unknowns should be included in the contingency to mitigate their risk. There are multiple methods used in common practice to evaluate productivity factors, one of which is the Trapezoidal Technique.

ADEQUACY OF LABOR AND PROJECT DURATION

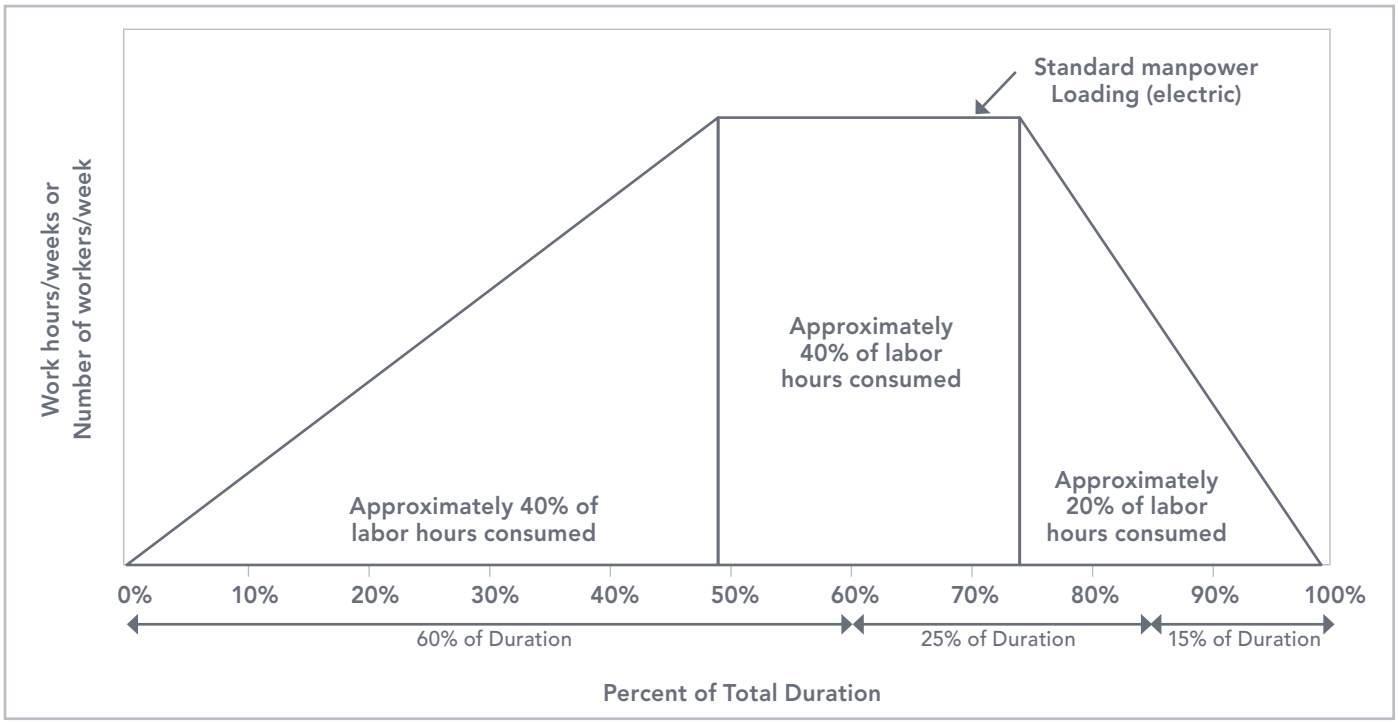
Each project has its own challenges and demands a variety of resources, such as people and time. One method of determining the adequacy of project duration is through the use of the Trapezoidal Technique (TT). This is a powerful method for determining optimum project duration, optimum peak manpower, and the expected rate of manpower consumption on a project. In TT, expected labor consumption is compared to project duration and the results are represented by a trapezoid, as pictured in Figure 2 on the following page. An adaptation of the manpower-loading curve, the trapezoidal technique allows a contractor to determine whether project work-hour consumption is on schedule. The TT can be used to calculate the peak workforce level and total duration of a project and to estimate consumption at each stage of a new project.

The TT operates under four assumptions: (1) all purchasing and contracting is on a competitive basis; (2) construction is executed on a regular 40-hour workweek; (3) apart from spot overtime, there are no accelerated procedures; and, (4) the main project objective is to control cost.

The trapezoidal technique is highly versatile and easy to use. It brings together multiple methods for estimating normal duration, peak manpower levels, and total labor consumption. Derived from the earned value system and the industry average manpower-loading curve, the TT is a single tool that contractors can use to quickly evaluate current work progress.

It should be noted that the trapezoidal technique is only valid for jobs performed by more than a single crew, typically indicated by projects with more than 2000 manhours. Smaller projects will tend to have a more consistent rectangular manpower-loading curve.

Figure 2: Trapezoidal Technique for Electrical Trades



The trapezoidal schedule can be divided into three time periods: the build-up, the peak, and the run-down period. Manpower is gradually increased to the peak level during the build-up. Figure 2 depicts a manpower-loading trapezoid for electrical trades. Since electrical work peaks later than other trades, the peak manpower is reached after a period of build-up which occurs in the first 60% of project duration. Moreover, during the peak period, the peak manpower level is sustained. This period contains the greatest amount of risk, as 40% of the manhours are used in a short period of time. Managers should closely monitor productivity and the rate of manpower consumption during the peak period.

The final period of the trapezoid is the run-down. During the final 85 to 100 percent of the project duration, manpower is gradually decreased from the peak level to zero.

USING THE TRAPEZOIDAL TECHNIQUE

The size and duration of a project are the primary forces that determine the amount of manpower needed for a project. If the size and duration of a project are known, it is possible to estimate the future manpower demands of a project during the early stages of project planning. **The TT can be used to estimate:**

- ◇ *total project hours*
- ◇ *project duration*
- ◇ *peak workforce level*
- ◇ *rate of manpower consumption.*

The area of the trapezoid represents the total manhours (scope) for a project. The height of the trapezoid represents the peak number of workers on the project The base of the trapezoid represents the duration of the project.

The trapezoid for a project can therefore be developed by estimating the total project manhours, the peak number of electrical workers on the project, and the project duration. The examples below are drawn from a well-executed electrical project.

ESTIMATING TOTAL MANHOURS

The total manhours determine the area of the trapezoid. To estimate the total manhours for a project, divide the total square feet by the appropriate production rate (in ft2/manhours). Production rates are best determined from actual company data but can also be drawn from industry average data as shown in Table 2 below.

$$\text{ESTIMATED TOTAL MANHOURS} = \frac{\text{FACILITY FT}^2}{\text{PRODUCTION RATE (FT}^2\text{/MH)}}$$

An example electrical project has a combination of warehouse space and office space (low-rise). The warehouse space occupies 87,500 ft2 and the office 12,500 ft2. As shown in Table 2, the production rate for the warehouse portion of the work is 44.01 ft2/mh, while the production rate for the office portion of the work is 13.96 ft2/mh. The calculation is:

$$\text{ESTIMATED TOTAL MANHOURS} = \frac{87{,}500\ \text{FT}^2}{44.01\ \text{FT}^2\text{/MH}} + \frac{12{,}500\ \text{FT}^2}{13.95\ \text{FT}^2\text{/MH}}$$

The area of the project trapezoid is 2884 manhours.

Table 2 shows example calculations of square foot/manhour. However, these calculations were performed based on the industry average at the time of data collection. This author recommends using proprietary data from your own company to make further calculations, as this table should serve primarily as a guideline and example. This table can also be used to check the estimated project manhours prior to bid.

Table 2: Average SqFt/Man Hour for Various Project Types

STRUCTURE DESCRIPTION	SF/MH	STRUCTURE DESCRIPTION	SF/MH	STRUCTURE DESCRIPTION	SF/MH
Commercial Stores	**23.80**	Hospital, Full Service	**6.00**	City Hall	**9.70**
Commercial Stores, Quality Retail	**14.90**	Office Building, Low Rise	**13.95**	Hotel, Low Rise	**25.95**
Market Buildings	**22.95**	Office Building, High Rise	**17.30**	Hotel, Mid Rise	**21.35**
Recreational Buildings	**20.45**	Warehouses	**44.00**	Hotel, High Rise, First Class	**19.35**
Schools, Elementary and High	**8.70**	Parking Lots, 2.5 FC	**149.00**	Hotel, High Rise, Deluxe	**17.95**
College Buildings	**13.80**	Garages, 5 FC	**98.40**	Hotel, High Rise, Luxury	**14.90**
College Dormitory	**21.75**	Assembly Buildings, Lt. Industrial	**22.55**	Housing, Low Rise	**42.60**
Clinic-MOB	**8.45**	Laboratory Buildings, Wet Science	**7.70**	Housing, High Rise	**29.80**

AVERAGE MANPOWER

Average manpower is the average number of workers required during each week of a project. This number may be determined from industry averages, or it can be calculated from the project size and duration by dividing the size of the project (in manhours) over the duration in weeks multiplied by forty. Forty represents the number of manhours per week.

$$\text{AVERAGE MANPOWER} = \frac{\text{SIZE OF PROJECT (MH)}}{\text{DURATION (WKS)X40}}$$

From the previous section, we know there are 2884 total manhours estimated for the example project. If the project has a planned duration of 18 weeks, the average manpower will be four workers per week, as follows:

$$\text{AVERAGE MANPOWER} = \frac{\text{2,884 (MH)}}{\text{18 WKS X40}} = 4.01$$

Average manpower is needed to estimate project duration and calculate the peak (maximum) manpower on a project. The peak manpower is represented in the trapezoidal technique as the height of the trapezoid, while project duration is shown by the area of the trapezoid.

ESTIMATING PEAK MANPOWER

The peak manpower or workforce determines the height of the trapezoid. During this period, the peak manpower level is sustained. Out of the three periods, this carries the most risk for the contractor. At this point, a large amount of manhours are being used in a short period of time. Managers should closely monitor productivity and the rate of manpower consumption during the peak period.

Peak manpower varies by trade. The maximum manpower for electrical trades is 160 percent of the average number of workers.

$$\text{ELECTRICAL PEAK WORKFORCE} = 1.6 \times \text{AVG \# OF WORKERS}$$

To determine the height of the trapezoid, estimate the peak number of workers on the project. The peak number of workers varies by trade. The example project is an electrical project with an average workforce of 4. The peak workforce for that project will be:

$$\text{ELECTRICAL PEAK WORKFORCE} = 1.6 \times 4 = 6.4$$

The height of the trapezoid will be 6, indicating that there will be 6 workers during the peak of the project.

ENSURING ADEQUATE PROJECT DURATION

Project duration is represented by the base of the trapezoid. The duration may already be known to the contractor. If not, it can be calculated by dividing the estimated total manhours by the average number of workers on the job and then multiplying by 8, the number of hours worked per day.

$$\text{PROJECT DURATION (DAYS)} = \frac{\text{ESTIMATED MANHOURS}}{\text{AVG \# OF WORKERS X8}}$$

For the example project, there are 2884 estimated manhours and the average number of workers is 4. The calculation for project duration is:

$$\text{PROJECT DURATION (DAYS)} = \frac{\text{2884 MH}}{\text{4 WORKERS X8}} = \text{90 DAYS OR 18 WKS (5 WORK DAYS/WK)}$$

The project duration is 18 weeks – the same as the base of the trapezoid.

ESTIMATING BUILD-UP, PEAK AND RUN-DOWN PERIODS

The build-up, peak, and run-down periods of a project can be estimated from the typical industry standard trapezoid for that particular trade.

$$\text{ELECTRICAL BUILDUP PERIOD} = 0.6 \times \text{TOTAL PROJECT DURATION}$$

$$\text{ELECTRICAL PEAK PERIOD} = 0.25 \times \text{TOTAL PROJECT DURATION}$$

$$\text{ELECTRICAL RUNDOWN PERIOD} = 0.15 \times \text{TOTAL PROJECT DURATION}$$

In the example project, the total project duration was determined to be 18 weeks. **The calculation for the three periods is:**

$$\text{BUILDUP PERIOD} = 0.6 \times 18 = 10.8 \text{ WKS}$$

$$\text{PEAK PERIOD} = 0.25 \times 18 = 4.5 \text{ WKS}$$

$$\text{RUNDOWN PERIOD} = 0.15 \times 18 = 2.7 \text{ WKS}$$

ALTERNATIVE METHOD FOR ESTIMATING PROJECT DURATION

An alternative method for estimating project duration is to use another publication by this author entitled Normal Project Duration, published by the National Electrical Contractors Association (NECA), and demonstrated in Table 3 below. This method shows the relationship between project size (in terms of work hours) and project duration (in weeks) for industry average and three types of projects: Commercial, Industrial and Institutional.

If estimators wish to check the adequacy of the contract's project duration, they can use Table 3 below to compare it to three project types and the industry average. In the example calculated above, the project's total manhours amounted to 2,884 hours. If the estimator compares this to the data on commercial projects in Table 3, it will show that the project falls at the interval between 2000 and 4000 manhours, which corresponds to a duration of 15-20 weeks. Thus, the example project is of adequate duration. It is important to note that institutional projects have, by far, the highest values for duration, especially at lower manhours.

Table 3: Summary

PROJECT SIZE (WORKHOURS)	PROJECT DURATION (WEEKS)			
	INDUSTRY AVERAGE	COMMERCIAL	INDUSTRIAL	INSTITUTIONAL
1000	14	12	17	30
2000	18	15	19	34
4000	23	20	21	39
6000	27	24	22	42
8000	30	26	24	45
10000	32	29	24	47
12000	35	31	25	48
14000	37	33	26	50
16000	39	35	26	51
18000	40	36	27	52
20000	42	38	27	54
22000	43	39	28	55
24000	45	41	28	56
26000	46	42	29	56
28000	48	43	29	57
30000	49	45	29	58
35000	52	47	30	60
40000	54	50	31	62
45000	57	52	31	63
50000	59	54	32	64
55000	61	57	32	66
60000	63	59	33	67
65000	65	60	33	68
70000	67	62	34	69
75000	69	64	34	70
80000	71	66	35	71
85000	72	67	35	71
90000	74	69	35	72
95000	75	70	36	**73**
100000	77	72	36	**74**

ESTIMATING MANPOWER CONSUMPTION

Manpower consumption can be calculated for the three periods by multiplying the percentage consumption of manpower by the total manhours. While industry data have been used for the example, it is highly recommended that actual company data be used for such calculations. This will increase the accuracy of the results.

Well-executed electrical projects consume approximately 40 percent of the total manhours during the build-up period, an additional 40 percent of the manhours during the peak and a final 20 percent of total manhours during the run-down. **The equations for calculating electrical manpower consumption are shown below:**

ELECTRICAL MANPOWER CONSUMPTION (BUILDUP PERIOD)=0.4 ×TOTAL MANHOURS

ELECTRICAL MANPOWER CONSUMPTION (PEAK PERIOD)=0.4 ×TOTAL MANHOURS

ELECTRICAL MANPOWER CONSUMPTION (RUNDOWN PERIOD)=0.2 ×TOTAL MANHOURS

For the example project, the manpower consumption for the three periods will be:

ELECTRICAL MANPOWER CONSUMPTION (BUILDUP PERIOD) =0.4 ×2884
=1153.6 MANHOURS

ELECTRICAL MANPOWER CONSUMPTION (PEAK PERIOD)=0.4 ×2884
=1153.6 MANHOURS

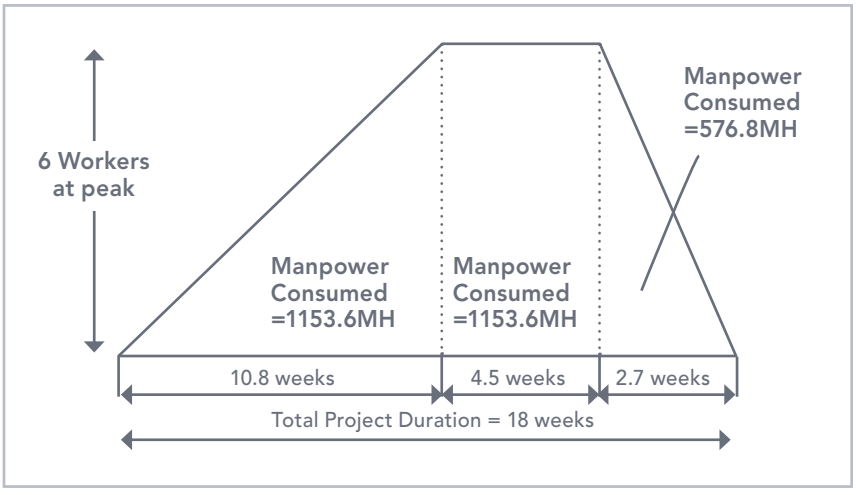
ELECTRICAL MANPOWER CONSUMPTION (RUNDOWN PERIOD)=0.2 ×2884
=576.8 MANHOURS

CREATING A FINISHED TRAPEZOID

Figure 3 was developed using the results from the example project. The peak number of workers is identified on the vertical axis. The project duration and the build-up, peak and run-down periods are identified on the horizontal axis. The number of manhours consumed during each period is identified by the area of the trapezoid.

The trapezoidal method can be used as a graphic control tool before, during, and after construction. By reviewing the project trapezoid, contractors can effectively manage their quantity of labor.

Figure 3: Trapezoid for the Example Project



CHECKING SCHEDULE COMPRESSION

Table 3 above can also be used to check for schedule compression/acceleration. It should be noted that the information provided in Table 3 is derived from statistical analysis, subject to a margin of error of ± 10% of the given duration. If the contract duration is lower than the value prescribed in the table by a factor greater than 10% of the original prescribed value (e.g. a 14,000 hour Institutional project with a duration of 30 weeks) then the contractor must adjust manhours to reflect the need for working overtime or utilizing two shifts. Contractors should avoid overmanning as a schedule acceleration technique due to its considerable inefficiency when compared to overtime or shiftwork.

IMPACT OF CHANGE ORDERS ON THE TRAPEZOIDAL TECHNIQUE

The figures below (4A through 4D) detail the impact of change orders on the trapezoidal technique. Change orders frequently include added scope (i.e. the area under the curve is greater than the original base scope), and occasionally include time extension. Figure 4A shows that the added scope occurred during the run-down period and caused a time extension. Figure 4B represents slightly more impact than 4A, because of the slow build-up coupled with added scope during the run-down period. On the other hand, figure 4C presents a scenario where the change order is issued during the peak period, causing an extension of the peak period. Figure 4D presents an extremely impacted project caused by slow build-up coupled with added scope during the run-down period.

Figure 4A: Minimum Impact: added scope is performed during the run-down period

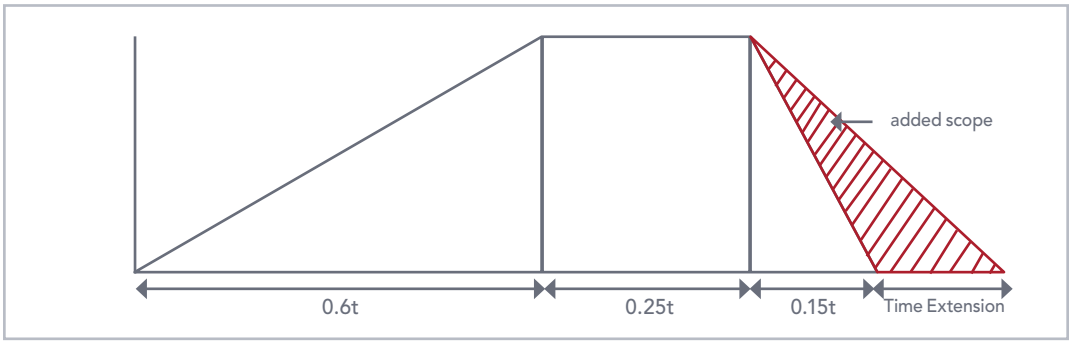


Figure 4B: Minimum Impact: slow build-up in addition to added scope during the run-down period

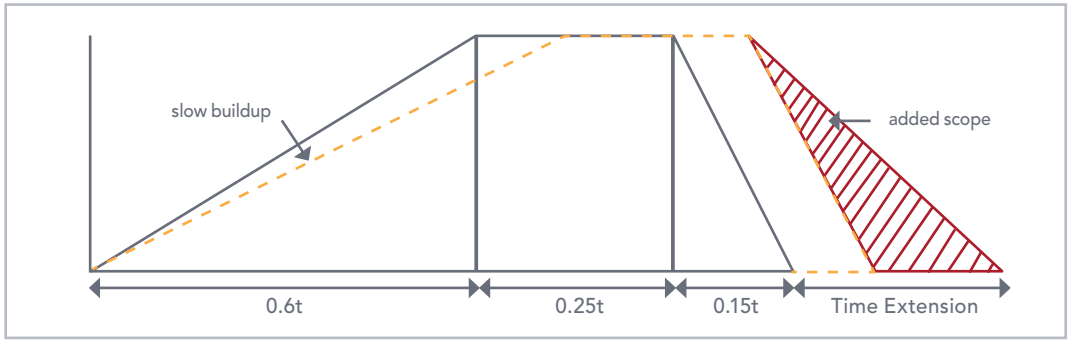


Figure 4C: Severe Impact: extended peak period

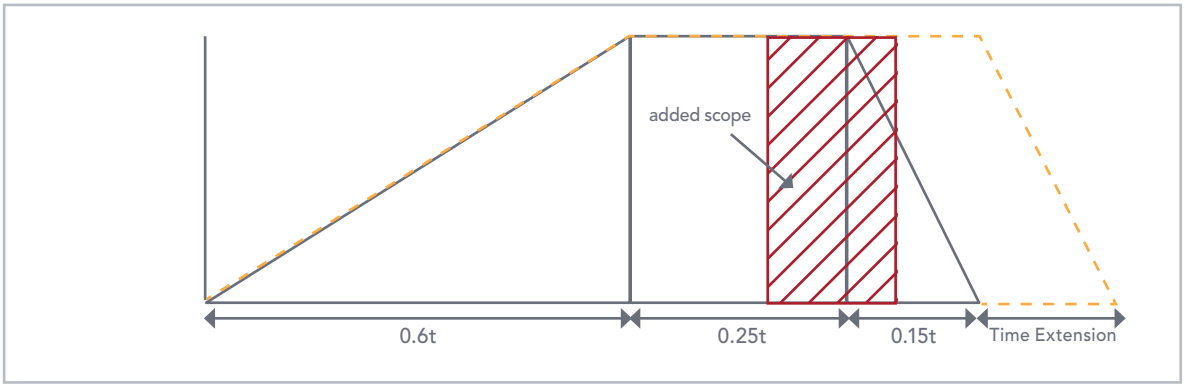
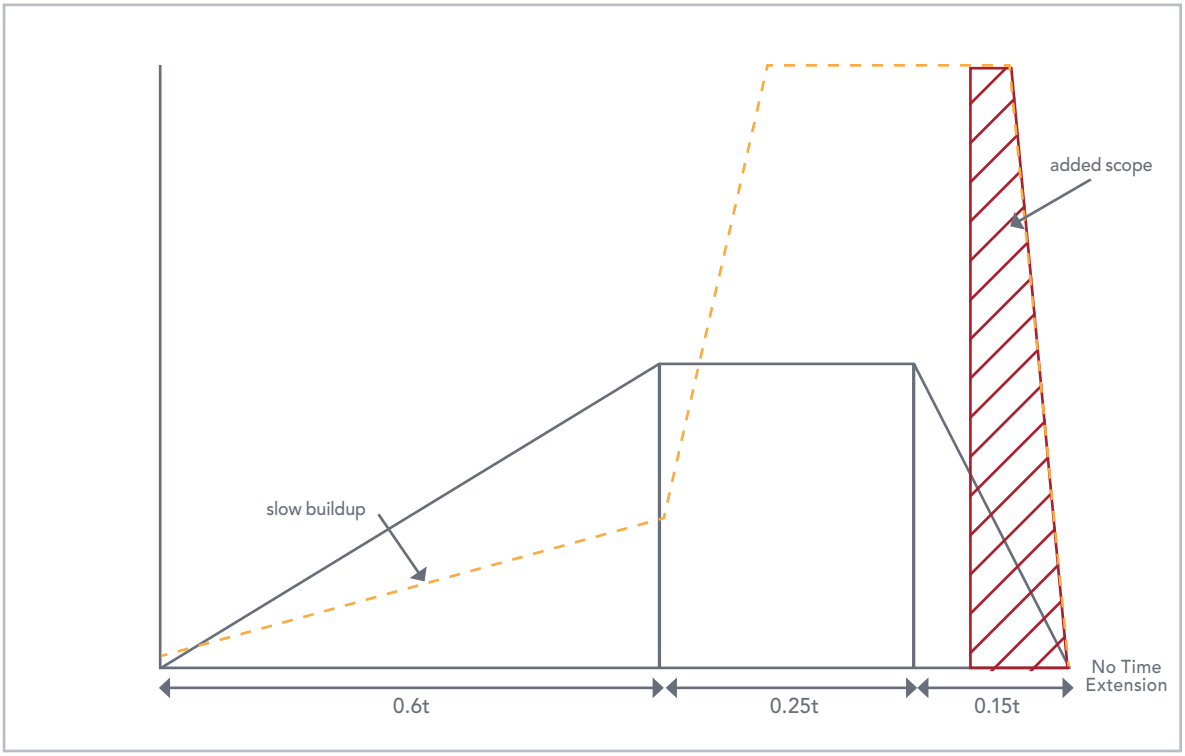


Figure 4D: Extreme Impact: slow build-up in addition to scope increase at the run-down period



ADEQUACY OF WORK AREA

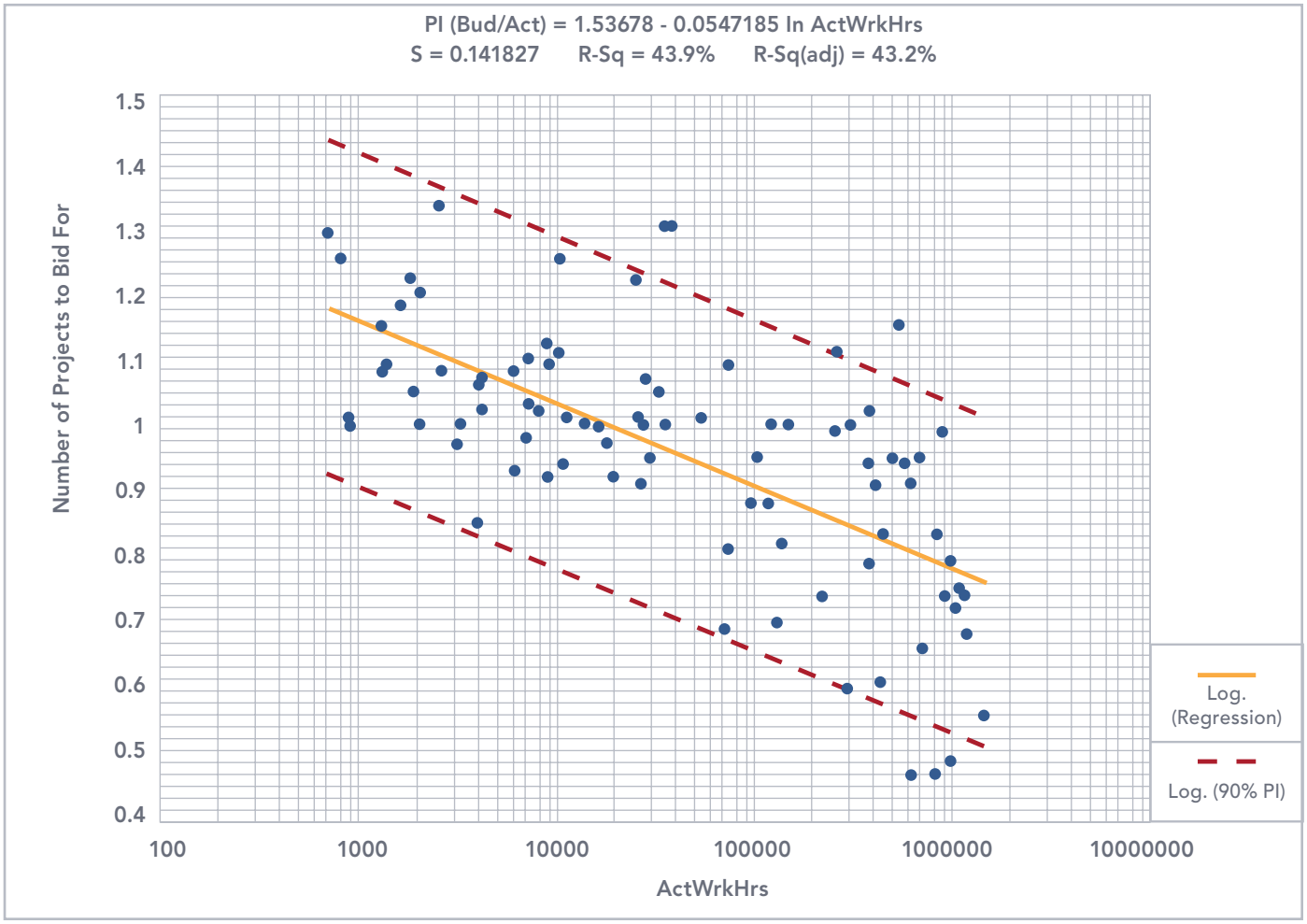
It is documented in previous research from this author that a worker needs between 150 and 300 sq. ft. of net space in order to perform work productively. Table 4 to the right shows the relationship between project complexity and the amount of space needed.

If the space available on a project is insufficient for the complexity of the project, then an estimator must update the contingency to reflect the stacking of trades that will occur.

Table 4: Project Complexity and Corresponding Density Levels

PROJECT COMPLEXITY	DENSITY LEVELS
Simple Projects (commercial, schools, etc.)	150-180 square feet/worker
Average Projects (high-rise office space, etc.)	180-250 square feet/worker
Complex Projects (hospitals, institutional, etc.)	250-300 square feet/worker

Figure 5: Productivity vs. Total Work Hours



SIZE EFFECT ON LABOR PRODUCTIVITY

This is an example of the "known known" type of factor. The project size is clearly defined and articulated in the contract and project documents and is also correlated with productivity, as shown in Figure 5 on the adjacent page. Productivity declines as project size increases. The figure also shows that optimal productivity (P=1) is achieved at project size of approximately 10,000 manhours. The x-axis of the graph is a natural logarithmic scale, which presents the actual hours extracted from copious actual project data. For projects with a size greater than 100,000 manhours, estimators need to adjust the estimate by a multiplier of approximately 0.92, and also increase the labor hours by a factor of 1/0.92 or 8.7%.

ESCALATION OF LABOR AND MATERIAL COSTS

For projects that span longer terms (years, rather than weeks or months), a factor that must be considered is the potential increase in costs for labor and materials. Escalation of labor costs is relatively easy to prove, especially for union contracts. Delays cause some (or many) activities to be performed at later dates.

In many instances, the contractor will pay wages at higher rates than originally planned and bid. As a result, increased labor cost is calculated by multiplying work hours utilized during the delay period by the difference of actual wage rates and what would have been paid. Also, as in the case of any other claim issues, the contractor must prove the actual cost and what the work would have cost if there had been no delay.

A useful proof is always a new union agreement. Another useful tool that can be used for forward pricing is to use Engineering News-Record's skilled labor price Index or Common Labor Price Index. The labor index contains hourly union wage rates for 22 different trades in 34 cities and open-shop wage rates for eight trades in various regions in the U.S. and Canada.

Table 5 to the right shows the changes of Skilled Labor price index from 1998 to 2012, as first published in ENR's March 2012 issue.

Table 5: ENR Common Labor Price Index data

YEAR	PRICE INDEX
1998	11835
1999	12243
2000	12547
2001	13066
2002	13669
2003	14075
2004	14684
2005	15284
2006	15943
2007	16521
2008	17084
2009	18016
2010	18502
2011	19079
2012	19472

CONCLUDING REMARKS

For the last 30 years, construction bidding has become more and more competitive. Estimators typically use their intuition and judgement not only to decide whether to bid or not to bid for certain projects but also to decide the percentage of contingency to allocate to their markup.

This document has been created to establish a formal method of assessing estimates and bids prior to bid, with the goal of improving hit-rates. This document also provides a methodology for adjusting labor hours to reflect project risks due to factors that are both known knowns and known unknowns. The best use of the information provided herein is for each electrical contracting firm to establish its own thresholds based on internal company data. This is recommended because the examples presented in this document have been derived from industry data and national averages and are not company-specific.

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