

Change and the Loss of Productivity in Construction: A Field Guide



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Preface

We are learning more about change, change management and change impacts all the time as the project management and legal fields evolve. We will therefore regularly revise this field guide, and would welcome your feedback to improve it.

Contact Professor Ibbs at (510) 420-8625 or Bill@TheIbbsConsultingGroup.com to provide such feedback or learn more about the topic of change.

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Part I:

Purpose of Guide



Thanks for your interest in managing change during construction. Construction is such an interesting field because it combines the technicality of design, the business savvy required for finance, incredible organization, and especially the people skills and leadership to manage dozens, if not hundreds, of people with competing interests. The people assigned to a construction project can make it a success, or allow it to fail. Everyone from the superintendent, to the project manager, to the laborer has a major effect on the jobsite.

This guide aims to give an introduction to change on construction sites. It's written primarily for the contractor's purpose, and aimed at the management level, both in the field and in the office. While experience is the best teacher in the field of construction, there are common terms, industry standards, and common estimations that are useful to know. This field guide is also an excellent introduction to field productivity and change management for students. It gives a general overview of productivity factors, types of change, the importance of managements' actions and decisions, and how to quantify productivity losses.

Field guides in general are not meant to be read through like a regular book off your shelf, but instead are for quick, efficient referencing. There are many different topics covered, and if you want more in-depth information look through the references, where there are many different of resources to give you more reading.

The main source of information for this field guide is a dissertation written by Dr. Seulkee Lee in 2007. The title of her dissertation was "Understanding and Quantifying the Impact of Changes on Construction Lab Productivity: Integration of Productivity Factors and Quantification Methods". This 800-page dissertation goes in-depth into the current research available and gives a detailed look at many of the methods for quantifying productivity losses. The dissertation was a compilation of dozens of source articles. This field guide is aimed to be a boiled-down, accessible version of the same information. Obviously, there is not the detail that is available in her dissertation, but

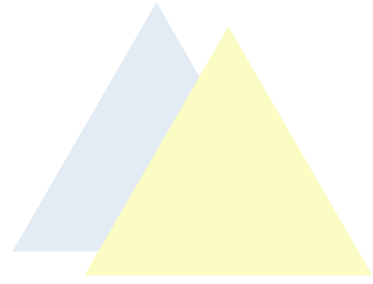
instead provides quick, easy to use information at your fingertips. For more detail, please see the referenced dissertation in the bibliography.

As stated before, there is much research on productivity losses in construction. Construction is one of the largest industries worldwide and trillions of dollars are spent annually on buildings, roads, bridges, power plants, and treatment facilities. As technologies and populations grow, this demand will also grow. Productivity is a significant portion of these costs and can be the difference between a successful project and a financial disaster.

We hope this field guide gives you the information you need to gain perspective on what change is and the possible effects it can have. Keep in mind that all of the methods presented are generalized and it is important to remember that every job is unique and will run into its own problems. Many of the methods and factors described will have slightly different effects on each job, and it is necessary to incorporate the unique characteristics of your project when estimating the effects of change.

We cannot stress too much that the guidelines presented are approximate. You may encounter rebuttal and rejection from the other party in using them, in which case it may be advisable to retain technical and legal help to pursue further negotiations.

Part II: Defining Change and Productivity Factors



Chapter 1: What is Change?

Chapter 2: Causes of Change

Chapter 3: Changes and Cost

Chapter 4: Recognizing and
Handling Change

Before being able to quantify the effect that a change has on your project, it is important to understand what is considered a change and to be able to identify what kinds of effects you can expect to see. Changes not only affect the activities that are directly impacted, they may have indirect, downstream impacts. Sometimes the full effects will never be realized. However, it is important to be comfortable at realizing where symptoms of change can occur, as well as understanding the potential costs, both in time and money.

Changes have a cause. Recognizing this cause is important to demonstrate, as well as using the contract documents to find who is liable for that change. The damages caused do not have to be as rigidly defined, but can be estimated. To be able to successfully estimate the damages, you have to be able to recognize both the immediate losses as well as the ripple effects.

Chapter One of this field guide will give you a general idea of what change is and some common factors that affect productivity. These factors are grouped into seven categories. While each factor is put into one category, it is possible for factors to have noticeable effects in multiple. There are factors beyond those listed that can have their own, individual disruptions.

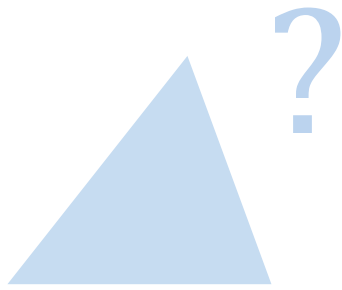
Chapter Two presents many different types of changes and their characteristics. This should allow you to be able to present the type of change factually. The more information you have on the change, the more likely you are to have the owner approve the costs. By knowing the common types, characteristics and sources, you should gain the information you need to diagnose the disruption, gain approval and keep your project moving.

Chapter Three goes into the costs, both direct and indirect, of a change or disruptive event. There can be costs to both time and money. There are additional costs associated with the increasing number of changes a project experiences. These costs are easy to overlook, but can be as large, if not larger than the direct costs associated with a change.

Chapter Four describes ways to recognize common triggers of change, as well as different ways that managerial actions can improve or worsen conditions. The disruption model is a useful tool for both determining the root cause of a problem, as well as identifying cascading cycles that can magnify the effects of a change. By understanding these cycles, it is possible to stop them and remedy problems as they occur without causing added disruptions. Also, managerial actions are proposed to understand how to end these cycles. This includes decisions from the contractor, owner, architect and engineers. It is important to understand the necessity for swift and effective action when a disruption occurs on a job site.

Part II aims to give a general overview of change and the types of factors that will affect productivity on a job site and how to handle these events. The information is purposefully general, as each jobsite is unique and it is important to identify the characteristics that are individual to your job. Remember this as you read through the productivity factors and learn to identify how your job's specific characteristics will alter the effects.



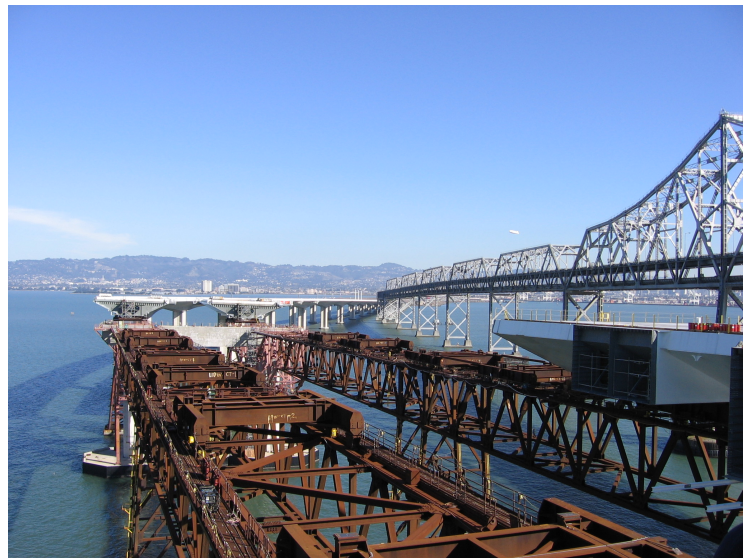


What is Change?

- Introduction
- Defining Change and Productivity
- Seven Categories of Productivity Factors
- Wrapping Up

Chapter Learning Objectives

1. Understand what change is and how it can affect your job
2. Learn to identify the results from different types of changes
3. Recognize different factors that will impact productivity



What is Change?: An Introduction

Changes, in many different forms, are a major part of construction. Despite their frequency, contractors and owners often disagree on the impact, and the liability, when they occur. It is important for a contractor to recognize the full impact of a change early so that both parties can agree on an accurate cost of the change quickly. While this often does not occur, it is in the best interest of all parties to understand the implications of a change so that steps can be taken to remediate the damage. Being fully aware of the change and its implication, you can have a much stronger argument for an accurate estimate of the costs. Additionally, if your change does escalate and go to claim, the additional understanding and information will give you a major advantage.

While the direct costs of a change can be very apparent at the time, there are indirect costs that are less clear. Besides the clear costs of materials, and even direct labor costs, there are productivity losses that are associated with changes that are often not taken into account. These will be defined later in this chapter and discussed further in Chapter Three.

This chapter aims to give a clear introduction to change and productivity, and give you a better understanding of how these can impact your project.

Defining Change and Productivity

Defining change is not a straightforward task. In construction, change is often synonymous with change order, but there are many other actions and events that should be considered when looking at changes on a project. In this guide, we will define **change** as any action, incidence or condition that makes differences to an original plan or what the original plan is reasonably based on (Lee, 2007). While changes orders are

Change – Any action, incidence or condition that makes differences to an original plan or what the original plan is reasonably based on

included in this definition, not all changes become change orders.

If changes go unnoticed by management, or if changes are not fully recognized in the change order, the full impacts of the change will not be documented. This field guide looks at changes, not just change orders, to include all possible impacts, both recognized and those that are missed.

As previously discussed, changes not only can add labor and material costs, but also affect a job's **productivity**, which can have a large cost in both time and money. Productivity is the amount or units of work completed from a certain amount of time. For example if a six-person crew can product 350 square feet of slab formwork in eight hours, the productivity is:

Productivity – efficiency, both labor and equipment; output vs. labor-hours input

$$\text{Productivity} = 350 \text{ SF} / (6 * 8 \text{ hours}) = 7.3 \text{ SF/labor-hour}$$

It is important to understand what productivity is, so that you can successfully measure the losses. Reasonable estimates will allow you to maximize the payment you will receive for the change. The different impacts and calculating the losses will be discussed further in Chapter Three, but in the next section we will talk about different factors that affect productivity rates.

Seven Categories of Productivity Factors

A productivity factor is a condition that influences productivity. There are different types of productivity factors that are affected by disruptive events. These disruptive events often generate a loss in productivity, which then in turn can cause another disruption. The different types of productivity factors can be categorized into seven different groups:

1. Project and Contract Factors
2. Location and Environment Factors
3. Project Team (Owner, Contractor, and Architect) Factors
4. Managerial Actions and Decisions During Project Execution
5. Disruptive Events and Signs on Sites
6. Human (Worker) Reactions
7. External Factors

Each of these categories has a different affect on productivity, some with direct effects, while others are more indirect. Some will affect the project immediately and others will take longer to have a measurable impact.

Remember that many of the below listed factors are not exclusive to one category. Additionally, each factor will have different effects on depending on the characteristics of your project. To be able to give you a general idea of what the categories include, there are many characteristics of each factor listed. The different factors are some of the possible reasons for variances in productivity.

Project and contract factors are generally determined before the project begins and will define the basis for estimating time and cost. Factors in this category include:

- Project size, scope, duration and budget
- Complexity
- Project type (hospital, warehouse, commercial, residential)
- Regulations and building codes
- Multiple contracts
- Project delivery system
- Contract type
- Construction methods
- Special requirements

Location and environmental factors are also normally determined before the project starts, and are based on assumed conditions. However, assumed conditions can unexpectedly change, such as unusual weather events, or changes in the local economy. Factors in this category include:

- Geological site conditions
- Transportation network (commuting considerations, logistical support, traffic and site access)
- Weather patterns (temperature, humidity and season variability)
- Local labor climate
- Local communities and cities (size, attitude and economy)

Project team factors are based on the systems and practices of each of the people involved on the working team. These factors affect the estimation of productivity and the ability of the team to manage and adapt to changes. These factors include:

- Contractor and subcontractor business systems and practices
- Project manager (experience, familiarity with project type, time spent on project)
- Owner, architect/engineer, construction manager systems and practices (experience, familiarity with project type, communication, timely decision making, procedures and systems for responses)
- All involved (working relationships, partnership, attitudes, previous working relationship)

Managerial actions and decision factors are the impacts created by the efforts taken by the management when changes happen. Proper actions can minimize the impact, but sometimes the only option is one that will decrease productivity. Some actions can themselves cause other events to occur, generating further delays. This will be further discussed in Chapter Five. These factors include:

- Contractor decisions and responses
 - Acceleration
 - Changes in work sequence
 - Support work (supply of tools, equipment materials, information and directives, proper working conditions and site management)
 - Ratios of crews and supervisors
 - Coordination between trades, subcontractors and shifts
 - Management of suppliers
- Owner decision and responses

- Change orders
- Acceleration orders
- Processing of change orders, reviews and approvals
- Responding to RFIs, timely and proper engineering support
- Timely decision making
- Differing site conditions

Disruptive events and signs factors are the symptoms on the site when a job is experiencing disruptions. These factors will directly affect the productivity and contractors should be able to find the root causes and responsibility of the losses. Many of these factors will be discussed further in Part III. These factors include:

- Congestion/trade stacking
- Shortage in skilled labor
- Increased accidents, injuries, absenteeism and turnover rates
- Errors, mistakes and poor quality work
- Slower pace, increased breaks, waiting and delays
- Stop and go operations or out-of-sequence work
- Lost learning curve effect
- Bad weather and seasonal effects
- Rework

Human reaction factors address the ways in which laborers react in different disruptive situations. They add to the more direct causes discussed in the list of factors above. These factors will lower productivity and can lead to more disruption. These factors include:

- Fatigue
- Physical reactions to weather or work conditions
- Disturbed biological clock and sleep deprivation
- Clumsiness and adeptness
- Morale, motivation and negative attitudes
- Loss of the job rhythm
- Social and domestic issues
- Working without clear direction

External Factors are not related to the project, team, location, or workers, but nonetheless can have an impact on your job. These factors are unforeseeable and the project team has no control over the impacts. These factors include:

- *Force majeure* (unforeseeable conditions)
- Strikes, riots and wars
- National and global economy changes
- Political forces and international influences

Wrapping Up

It is clear that there are many different factors that need to be considered when trying to examine any type of change on a project. There are many different things that affect productivity, and it is important to recognize which factors can have an impact on your jobsite. Part III of this guide will go further into common factors and will give you insight into calculating the effects of these gains and losses. For now, the goal is to be able to recognize what can be a factor. Once you recognize a factor that could affect your job, you should track it. The more information you have available for estimating the cost of a change, the better.

The next couple of chapters aim to give you an idea of the different causes of change, and the different types of the associated costs. It is important to remember that this guide presents a general overview to help give you an introduction to the problems presented.

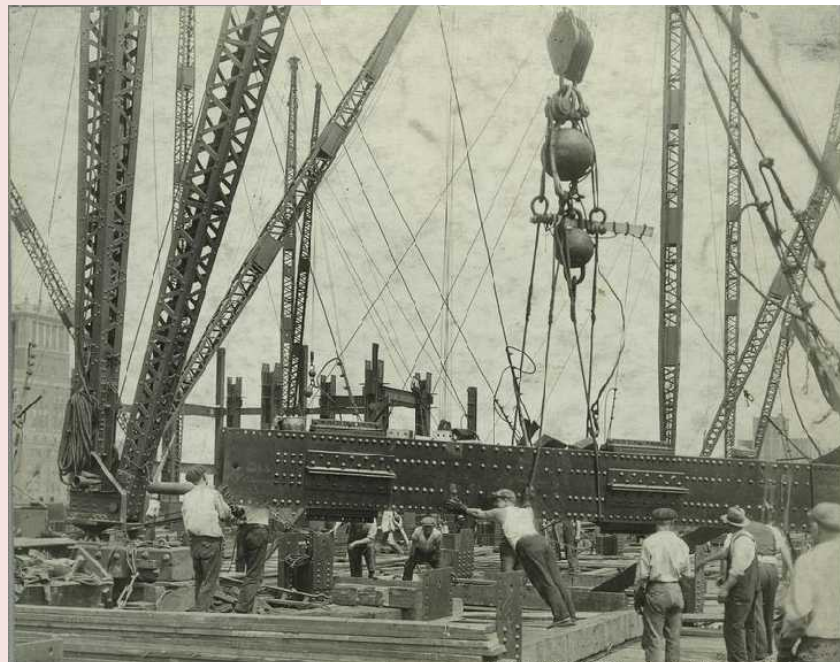


Causes of Change

- **Causes of Change**
 - Types
 - Characteristics
 - Sources
- **Factors that Magnify Losses**
- **Wrapping Up**

Chapter Learning Objectives

1. Understand the different types of changes
2. Look at common sources of change and their effects
3. Learn how different factors can alter the affects of a change



Causes of Change: An Introduction

As you read in the last chapter, there are many different ways productivity can be affected on your job. This chapter discusses some of the most common types of changes and their causes. To be able to identify the full extent that a change can have, it is important to recognize the impact it has on your project.

The impact of changes will be different for different types of work. For example, cold weather will affect work that requires fine motor skills more than it will affect manual labor. Keep in mind what trades are impacted and how that could change your schedule. Further, there are other events that can magnify the losses of a change, such as when the change occurs or the management practices of the contractor.

First, this chapter will present common types, characteristics, and sources of change. Later, factors that can magnify losses will be discussed.

Types of Change

While changes can be classified in many different ways, some common classifications are listed below:

- **Owner Acknowledged Changes versus Constructive Changes**
 - An owner acknowledged change is one that both parties (the contractor and owner) have agreed is a change.
 - A constructive change is a change that the owner does not acknowledge when it occurs, but it still has an impact. Action or inaction by the owner can be a constructive change in itself if the contractor is required to perform differently than the contract outlines.
- **Cardinal Changes versus In-Scope Changes**
 - A cardinal change is a change to the contract because the size or scope is outside what is included in the contract writing.

- An in-scope change is a change to the work that is already being performed.
- Contractors are generally not obligated to perform the work of a cardinal change.
- In public projects, cardinal changes are illegal and considered new procurement.
- **Detrimental Changes versus Beneficial Changes**
 - While changes on a construction project are generally negative, requiring additional time or money, there are also beneficial changes that have positive impacts.
 - Beneficial changes can reduce cost, schedule, or degree of difficulty.
 - Detrimental changes reduce value or have a negative impact.
 - This classification is dependent on your point of view (what is positive to one person could be negative to another).
- **Required Changes versus Elective Changes**
 - Required changes may be necessary to meet basic business objectives, to meet regulatory or legal requirements or to meet defined safety and engineering standards.
 - Elective changes are proposed to enhance the project, but are more discretionary.

These are not the only classifications for changes, but are common distinctions. Changes often fall into more than one of these categories. Understanding the differences in these classifications can give you more information to present your justification for additional compensation associated with a change. Also, by understanding more about the type of change, it is easier to quantify the damages owed.

Characteristics of Changes

Beyond just the type of change, there are other characteristics that can help you identify the effects. These characteristics are:

- **Forseeability**

- Some changes are foreseeable in some degree, while others are completely unpredictable.
- Changes that are expected should be accounted for during estimating, such as standard seasonal weather effects.
- **Agreeability**
 - Contractors and owners often have different opinions regarding changes and some will consider a situation to be a formal change, while others may not.
 - Even when both parties accept a change, the amount of time and price awarded is often different.
- **Substitution or Addition/Subtraction in Project Value**
 - A change can take the form of either a substitution or an addition/subtraction.
 - Substitutions may not change the price of a project if done early, such as choosing a paint color.
 - Addition/subtractions are changes that alter the contract amount. That change in contract value should not be confused with the total cost of the addition or subtraction, which can be much higher. This is due to the indirect effects of the change.
- **Contractual Meanings of Changes**
 - The wording of the changes clause is an important part of a construction contract.
 - The provisions required to complete a change order, or define what constitutes a change are vital pieces of information to understand and agree upon before contract execution.

These characteristics further define a change on a project. Additionally, by understanding these characteristics, you are further able to identify whether a claim is legitimate, or whether it deserves compensation.

Sources of Change

There are three standard sources of changes on a project. They are:

- **Owner-Originated Changes**
 - Owners often need to add something to a project that is not specified in the base contract.
 - Owners also have the ability to change the design or move the project completion date.
- **Field-Originated Changes**
 - The most common sources of field-originated changes are “differing site conditions” where the physical condition on the site is either not what was expected or not apparent until construction progresses.
- **Third Party Actions**
 - There are also situations where modification is required by conditions beyond the control of the owner or contractor.
 - Examples include strikes, changes in regulatory requirements, delays in permitting, and damages from *force majeure*.

Each of these sources has costs and time impacts associated with them. Owner-originated changes have the clearest case for compensation, while the other two may need to be proven as unforeseeable. It is important to have a good idea of site conditions before estimating to make sure that there were no records or tests released during the bid process. Further, it is important to be up to date on regulatory codes and the permitting process to limit the amount costs associated with third party changes.

Proving a change claim can be a very expensive and difficult task, but the more information you have about the type of change, its characteristics and source, the more likely you are to receive fair compensation. Remember that these lists are general and each category is not exclusive. In fact, most events that occur on a jobsite will fit into more than one category on each of these lists. Later in this field guide, you will learn to quantify potential losses. It is beneficial to make conservative estimates when quantifying such losses because these situations can be very complex.

Now that you can identify different parts of a change, it is important to look at other factors that can magnify their effects.

Factors that Magnify Losses

The change alone does not define the amount of productivity loss or the associated costs. There are other factors that contribute to the losses and can magnify the total loss of time or money on your project. Some of these factors are:

- Timing of the change
- Complexity of the added work
- The amount of time it take to get the change formalized (processing time)
- Interdependencies among activities
- Intensity of the work and amount of room in the schedule
- Frequency and severity of design errors and omissions
- Management practices
- Lack of inspection and supervision by the architects and engineers

Any change order can affect the productivity on your site, but it is important to realize that the same change will have different consequences when these listed factors are changed. For example, a change that is recognized early in the project may have less cost associated with it than one that is found later.

To understand the full cost of a change, you should be able to estimate the other effects from the different factors and see if they magnify your losses further. Also, if multiple changes occur simultaneously, they can have a compounding affect on losses. This will all be discussed further in Part III of this guide.

Causes of Change: Wrapping Up

When identifying an event as a change, it is helpful to have as much information as possible to present the change to the owner. More specifically, determine

causation and the liability, and estimate the subsequent damages. Not only will this increase the odds of your change being acknowledged, but will help you to be able to quantify the full effects associated with that event. There are so many different factors that you must be aware of from the timing of the change to the trades being affected, but the more information you can have, the more you can strengthen your case.

This chapter discusses the main types of changes, their characteristics and sources, as well as looking at other factors that can magnify the losses of a change. These are important features to have when trying to quantify the damages resulting from the disruption. Finally, not all causes and types of changes are discussed here, but the broad categories laid out are common distinctions of changes that are found. Changes can fall into more than one category because they are often not clear-cut, well-defined instances, but complex events that can be hard to categorize. A lot of the clarity will come from experience.





Changes and Cost

- Introduction
- Direct Costs of Changes
- Indirect Costs of Changes
- Mathews Curve
- Wrapping up

Chapter Learning Objectives

1. Understand the direct and indirect costs of changes
2. Identify indirect costs and understand how they are impacted by change
3. Learn how to use the Mathews Curve to estimate added costs from multiple delays



Changes and Cost: An Introduction

Events that cause changes can have ripple effects throughout the rest of your project. The cost of a change is often underestimated because of all of the indirect costs that are often missed. By being informed of the ways a change can affect your site, you will have a better understanding all of the costs associated with changes, and if they are applicable on your site.

The true cost of a change is not necessarily the cost that is received in the change order, or the amount approved by the owner. The contractor might not even recognize the true cost of a change until the project is completed. Parties can also “cut a deal”, especially if fault is not clear. There are effects that changes can have on morale, productivity, and concurrent work, which are not easy to recognize, much less quantify. If you are able to identify these indirect costs, however, you are more likely to receive fair compensation for the changed work or event.

Direct Costs

Direct costs are the costs associated with the change itself, as well as the impact posed on adjacent unchanged work. This includes any resequencing of work that has yet to be completed and any productivity losses directly associated with the change. The US Army Corps of Engineers suggests the following checkpoints to identify the direct impact on your site (Corps, 1979):

- Has any activity been moved from a favorable to an unfavorable weather season?
- Are there now more activities in progress at a given time than before the revision?
- Have delays occurred such that phases of work will not be accomplished before other factors prevent the completion of work until the next favorable season?

You also need to be able to estimate the amount of time and materials that will be required to execute the change. Direct costs are generally easy to estimate, and don't require too much additional calculation than what industry professionals use to estimate any other type of work. These are the costs that are also the easiest to recover from the owner, because there is more concrete proof of their value and use.

Indirect Costs

Indirect costs include items like home office, jobsite overhead, interest and profit. This guide will also include productivity losses in this category. While these two different things are dealt with separately, they are both costs that are associated with change and they should be considered when quantifying the cost of a change.

Home office overhead, jobsite overhead and interest are costs important to include in changes where there the schedule is extended. Each of these is more costly as the time increases. For any change, the profit is generally added and it is standard to include profit on any change order calculation.

Productivity losses can be a large cost of a change. It is important that these costs be included in the overall valuation. Productivity losses are not easily foreseeable and they are hard to measure. There may be cumulative impacts on productivity from multiple inseparable changes as well.

Account for these losses if there is a high degree of interdependency between the changes and the base contract work. Part III of this field guide focuses on calculating the amount of productivity loss associated with different types of changes. In general though, change orders in the range of 5-10% of the budget should be reasonably expected. At some point, there can be added "ripple" effects. Courts have often sided with contractors, even when they waived their rights to compensation, and awarded such "cumulative impacts" on productivity losses.

Mathews Curve

The Mathews Curve is a rough model. It often will not be accepted by itself as a justification for compensation, but it can be a useful tool to reinforce another argument. It is used to estimate the increase in costs on a project due to increased amount of changes and disruption. This is additional to the costs of the changes themselves. Having multiple delays and changes can increase the project costs and can lower productivity.

The Mathews model takes the percentage of delay or disruption and calculates the percentage of increased cost that is associated with these delays. This is a way of roughly approximating the added costs that could be expected if multiple changes are experienced on your project. The model only deals with the costs due to delay or acceleration and does not include premium time and other factors.

The procedure to apply the Mathews curve (Figure 1) successfully is:

- Determine the total number of days of delays that occur during the job duration, but exclude contractor-caused delays.
- Determine the total contract time, as scheduled, without delays.
- Calculate the percent of disruption.
 - $\% \text{ Disruption} = \text{Total Delay Days} / \text{Total Scheduled Contract Duration}$
- Find the corresponding percentage of loss of productivity from the Mathews curve.
 - This percentage should be applied to all activities associated with the delays.
- The following conditions must be satisfied before the percentage of the curve is applied.
 - All items with measurable effects from the change have been removed and analyzed separately.
 - Fixed costs, such as materials or subcontractors are removed.

- The amount of days of delay can be measured.
- All costs prior to change have been removed.
- Concurrent items not affected have been removed.

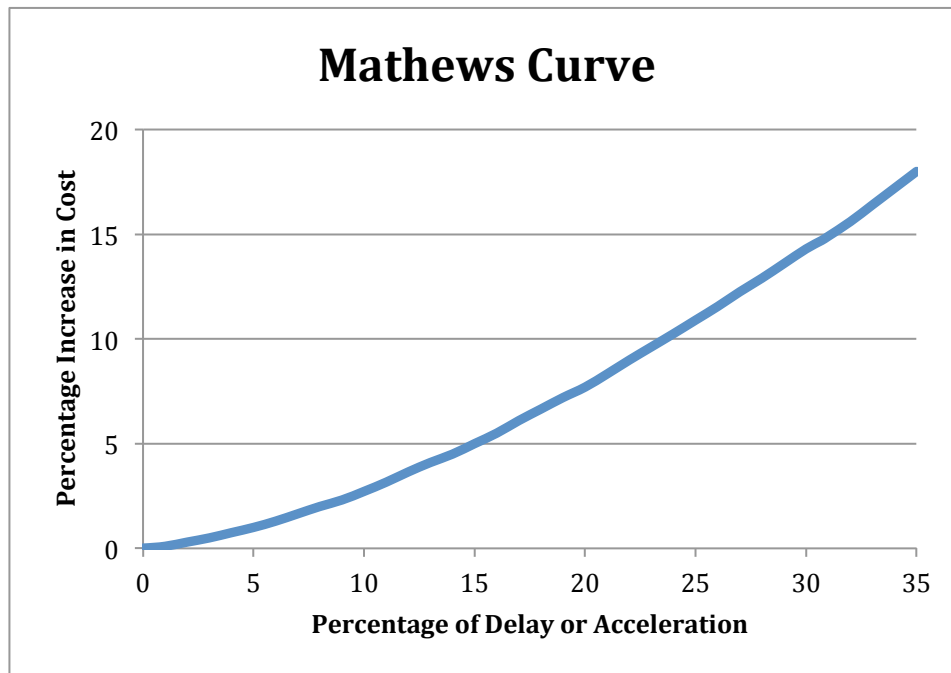


Figure 1: Mathews Curve showing the percentage increase in cost for the percentage of delay or acceleration, derived from Lee, 2007.

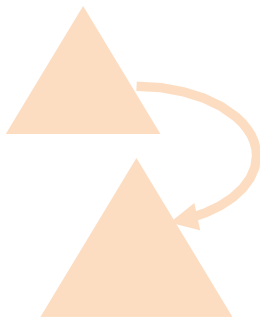
As you can see, there can be a significant increase in cost from a relatively small percentage of delay. It is important to keep this in mind when there are multiple change orders and owner-derived delays. This curve is just to be used as a guideline, and actual added costs will depend on the particular situation and variables that are unique to your job site. Make conservative estimates when estimating the lost costs.

Changes and Cost: Wrapping Up

There are anticipated and foreseeable costs associated with changes. You know how much extra material to anticipate and the general amount of time it will take to install it. What you cannot anticipate is the effects on other work, or the indirect costs from stopped time. This needs to be included in your estimation of the impact a change event has on your job.

The indirect costs are not only inclusive of the costs of added overhead and supervision, but also costs from a loss in productivity on your job site. Further, when there are multiple types of changes and delays, the cumulative effect will further add to the cost of your project. The Mathews curve is a very general guideline for the amount of added cost that can be expected when there are delays or acceleration on a construction job.



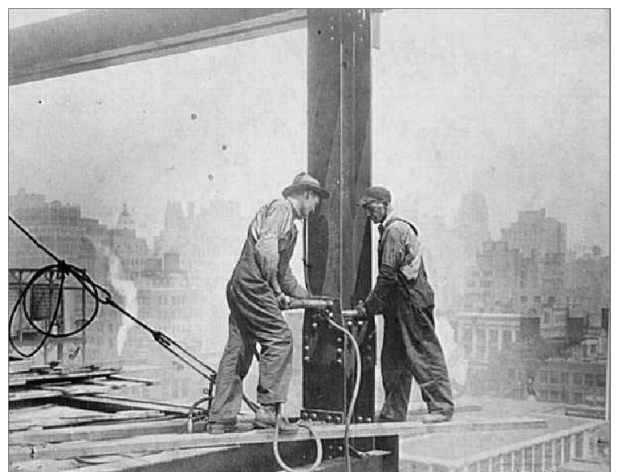


Recognizing and Handling Change

- Introduction
- Using the Disruption Model
- Expanded Disruption Model
- Contractors' Decisions: How to Proceed
- Owners', Architects' and Engineers' Decisions
- Wrapping Up

Chapter Learning Objectives

1. Learn the common triggers of change
2. Understand the cycles of change that can cause added productivity losses
3. Learn the important steps a contractor should take after a change
4. Recognize how management's actions are both triggers and dampeners of change effects



Recognizing and Handling Change: An Introduction

Now that you have a clear understanding of different types of changes, you may be wondering how to handle them. It is important to quickly recognize changes, as well as their common triggers, so that you can mitigate their effects, or prevent them from happening at all. The disruption model presented in this chapter is used to look at the root source of problems and to recognize when triggers can have effects on a project.

The actions and decisions made by management can either mitigate or magnify the productivity losses caused by change. It is management's responsibility to intervene when a project faces disruption and to fix the problems. Good decisions have the ability to get work running smoothly without major delays, while bad decisions have the ability to compound problems and generate further costs. It is important to note, however that some changes will have major effects regardless of management's actions and there can really only be a negative effect in those cases.

It is important to recognize what a change is and what the major triggers can be and then to act swiftly to avoid additional issues. This chapter aims to give you the tools you need to use a system map to see where disruptive events can occur and where the symptoms can be seen. Once a trigger is noticed or a change occurs, management must act to avoid causing additional harm.

Using the Disruption Model

The system map in Figure 2 shows the disruption model. The main sources of triggers come from location and environmental factors, managerial actions and decisions and external factors. These factors are further discussed in Chapter One.

Managerial actions and decisions can either magnify the total cost of the other events, or they can reduce the overall effects.

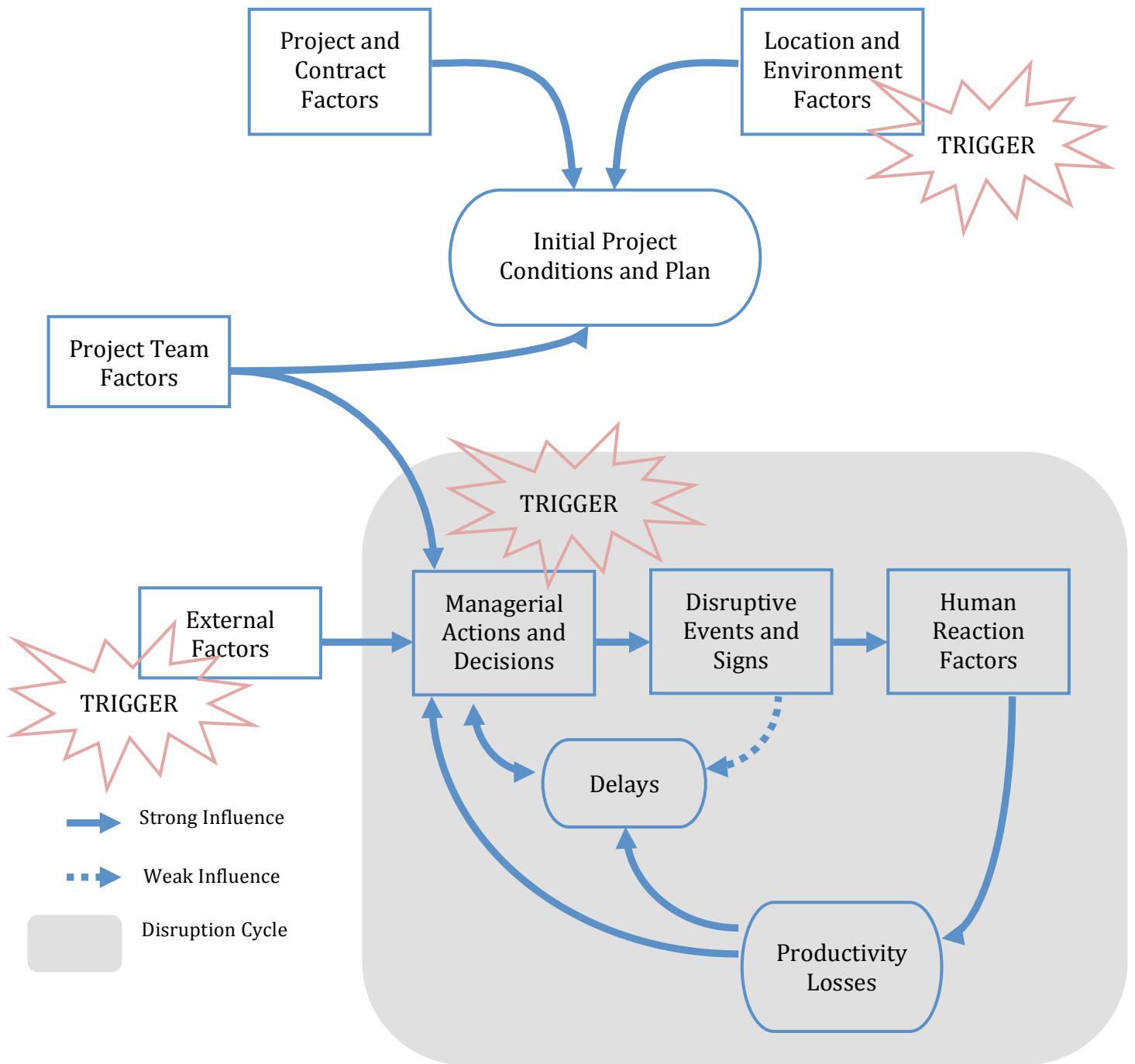


Figure 2: Comprehensive system map showing disruptions and influences between productivity factors, derived from Lee, 2007.

The above system map shows the influences between different productivity factors. It is a communication device that helps you and other people see that there are many different influences. The disruption cycle, shaded in gray, shows how one disruptive event can cascade and generate more delays. There can be added costs from one event if management makes bad decisions.

It is important to understand the interrelationships between the different productivity factors and know how they can affect each other. The factors that affect the immediate site are under the categories of:

- Disruptive Events and Signs
- Human Reaction Factors

The other factors are either decided before the project starts and influence the initial project conditions and plan or are external events that are generally uncontrollable. It is important to understand the common triggers of disruptive events, so that you are able to prevent changes from occurring.

Expanded Disruption Model

There are some limitations to the above model. An expanded disruption model was created to show cause and effect relationships and show different sources of events (Figure 3).

The top half of the model shows managerial actions and decisions, as well as events from external factors. Below the line are the immediate site factors. These events result in productivity losses and delays.

Even though this is the *expanded* disruption model, it is important to remember that it is not complete, but a general list of factors. There are many other triggers and symptoms on jobsites. Keep in mind that this list is not considered extensive and that one factor can have effects in multiple places.

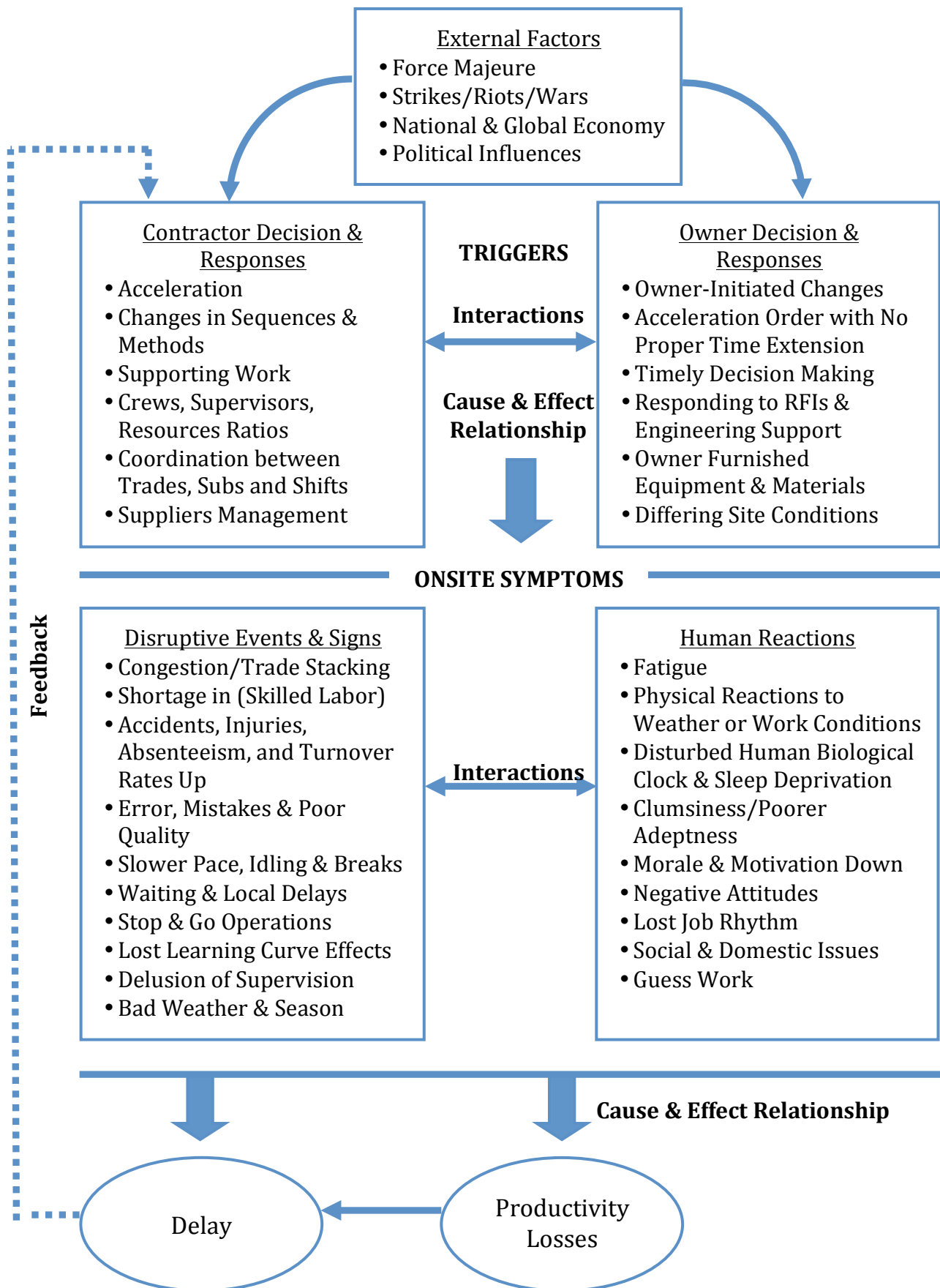


Figure 3: Expanded Disruption Model, derived from Lee, 2007

In the expanded disruption model, the triggers from the upper levels cause the onsite symptoms below. These cause delays, which will feedback into the decision level. This can create a feedback loop of delays and productivity losses if there are poor management decisions.

Both disruption models show that symptoms seen onsite can be the result of triggers from other sources. Identify these triggers so that the delay or disruption can be identified and remedied. If this disruption is the owner's liability, equitable adjustment can be argued.

A second key point of the disruption models is the feedback loop between delays and productivity losses and the management's decisions and responses. Breaking this loop with good decisions can stop further delays and costs.

Contractor Decisions: How to Proceed

It is a manager's responsibility to react quickly to a change, and to anticipate changes that have yet to happen. There are two major costs that affect a project, time and money. It is management's responsibility to minimize both. Sometimes there are no options that will result in maintained productivity, and management has to make a decision that will result in a loss of productivity.

Calculate anticipated costs quickly and to track associated costs immediately if a disruptive event is identified. If a rough estimate can be made and approved, delay can be minimized. Work can be resumed, but you should track the costs of this particular disruption separately from other project costs, so that losses can be recovered. By tracking the costs separately, it not only shows the direct costs of the change, but also can be used for recovering compensation for the full extent of the change.

Even before a change has been formalized, it is advisable to begin tracking additional costs separately so that it is possible for them to be recovered later. If these costs are not tracked, you are less likely to get compensated for them.

The most common way to make up for a delay from a change is acceleration. Acceleration is the addition of useful labor hours per week to complete the work faster than originally estimated. This can allow a project to get back on schedule when a change order occurs without time extension or when an owner wants an earlier project completion date.

Acceleration can be either directed or constructive. Generally the owner orders directed acceleration for part or all of the work to be completed faster than originally scheduled. This constitutes a formal change, and so directed acceleration is in itself, a change. Constructive acceleration occurs when the contractor has encountered delays, but is not granted an appropriate time extension.

There are four major ways to accelerate a project that will be discussed in much further detail in Chapter Five. These forms are:

- Overtime – the use of labor beyond the standard 8 hour per day, 5 day per week schedule.
- Overmanning – adding more workers to a crew than is typical for that type of work.
- Trade Stacking – having multiple trades working in the same area.
- Shift Work – adding a second crew of workers whose work is performed after the primary crew.

Each of these methods above will result in increased production, but as you will learn in Chapter Five, the increase is not proportional to the amount of labor-hours added.

It is also possible to resequence work or use out-of-sequence work if a delay is encountered that affects only one trade or area. Resequencing is risky and may result in decreased productivity, but can be the best decision in particular situations.

Finally, it is not only important to manage time and money, but also the work. Supporting work includes:

- Maintaining a supply of tools, equipment and materials

- Providing workers with up to date information and directives
- Ensuring proper and safe working conditions
- Proper site management
- Resource loading and crew ratios
- Coordination between trades, subcontractors and shifts
- Managing suppliers so materials are available when they are necessary

A main objective of this supporting work is to allow work to continue smoothly and efficiently. Additionally, by supporting the work, managers can make sure that they are not the cause of delays themselves. Any of the above listed items can be the cause of delay if they are not handled properly.

Owner, Architect and Engineer Decisions

Contractor decisions are not the only ones that can affect a job. As stated above, directed acceleration is an order from the owner to complete the work faster. Additionally, the owner, architect and engineers can have an impact, both positive and negative in many ways, including:

- Change orders
 - Frequency and size of change orders
 - Types of changes, whether scope, design or method
 - Timing of change orders
- Acceleration order
- Timely decision making
 - Time the owner, architects and engineers take to process, review and approve change orders
 - Time it take for architects and engineers to response to RFIs

If the parties are quick to respond and don't issue many change orders, a job can run smoothly delays from the owner can be avoided, but it is also possible for the owner, architect and engineer to hold up a jobsite if there is not an efficient flow of information. As a contractor, it is important to work with the owner, engineer and architect to communicate priorities and maintain a steady flow of information.

If information is necessary for the work to continue, inform the party that the information is needed. Also, formally give timely notice that this information is needed to continue on schedule and a delay can occur if it is not given. This is only applicable if the RFI, submittal, or other request was sent in with reasonable response time allowed.

Recognizing and Handling Change: Wrapping Up

Being able to know different productivity factors and how to define change is one thing, but being able to identify it on your site and take the corrective actions is another. Knowing the common triggers to disruption and productivity loss should help you to intervene before damages occur. Additionally, understanding the roles of the major players can help keep the flow of important information steady.

When disruptions do occur, swift action should be taken to alleviate any potential damages. This can be done by tracking the costs of the change separately, giving timely notice to the owner, and making sure that any RFI's or engineering decisions are communicated clearly within a reasonable amount of time. If these things are executed successfully, management has the ability to minimize the costs. If they are not, management can actually have a magnifying effect.

Part III: Quantifying Change and Loss of Productivity



Chapter 5: Acceleration

Chapter 6: Weather

Chapter 7: Learning Curve

Chapter 8: Multiple Factors

Chapter 9: Cumulative Methods

Now that you have a clear understanding of some of the causes of change and how to demonstrate the root cause of a problem, you should understand how to quantify the effect a change has on your project. Merely showing the owner proof that a change occurred will not result in a compensable payment for added work. You have to be able to quantify the effect on productivity to give an accurate estimate of how much it costs to finish the delayed work. The only way to do this is to have the tools and methods available for estimating the productivity loss that has occurred.¹

This part of the field guide aims to give you those tools and present the common methods that are currently used in practice to quantify the effect of changes and disruptions. Part III is initially broken up by the types of change, which include acceleration, weather and the learning curve. The methods in these chapters that are used to calculate productivity are considered discrete, and they only account for that one type of productivity loss or gain.

Chapter Eight focuses on methods that allow you to combine multiple factors together, without double counting or forgetting about interdependencies that are discussed in Part II. Finally, Chapter Nine presents some traditional methods that are used to quantify the effect of many different occurrences that are not unique or separable.

Keep in mind that with all of these methods, this guide aims to give a general overview of the available methods that are currently accepted in the industry. The methods are meant to be used merely as a guide and not as a specific rule. When applying any of these methods to your particular site, remember the unique factors that affect your job, and how these productivity metrics will be affected by those factors. Also, there is abundant research available on the effects of change on productivity, so if a particular method strikes your interest, please see the references of this guide.

By the end of this part, you should have a general introduction to many of the current ways to quantify productivity gains and losses on your job. You should have a good feel for the general effect that different changes can have on your project. This can help throughout your project from estimating to close-out.

¹ You also have to demonstrate owner liability, but that is beyond our discussions here.



Acceleration

- Introduction
- Overtime
- Overmanning & Trade Stacking
- Shift Work
- Wrapping Up
 - Comparison Table
 - Flow Chart

Chapter Learning Objectives

1. Understand the most common forms of acceleration
2. Define the unanticipated costs associated with acceleration
3. Discuss the productivity losses of each form of acceleration
4. Analyze the types of acceleration to find the best type for a specific change



Acceleration: Introduction

Quick Facts:

- 30% of all construction jobs experience some form of acceleration (Leonard, 1988).
- 9 of 10 contractors have had experience with completing a project faster than anticipated.
- All forms of acceleration decrease overall project productivity.
- Acceleration can be very costly.

Chances are you are well-acquainted with **acceleration**. Acceleration is used to increase the productive labor-hour on a job. It can be implemented for many different reasons. For example, acceleration is used to complete work earlier than scheduled, to make up for an inadequate time extension for a change, or to make up for a material delay. The frequency of this issue does not diminish the overall effect it can have on a project and it is important to know how different forms of acceleration will affect a project.

Acceleration – Increasing the productive hours on a job, adding more resources, resequencing the work, etc. to complete work faster than originally anticipated.

There are three main methods for accelerating a project:

- **overtime,**
- **overmanning & trade stacking**
- **shift work.**

Overtime – work that extends beyond the standard 8 hour day and 5 day week.

Overmanning – Adding more workers to a crew than is typical for the type of work.

Trade-Stacking – Multiple trades working in the same space.

Shift Work – Adding a second crew of workers whose work is performed after the primary crew.

While each of these methods will increase the daily output on a job, it is not the case that doubling the amount of hours, or doubling the worker-power will double the output. There is a loss of productivity that is associated with each method of acceleration, which will be discussed in depth later in the chapter.

Questions Proposed

- Why is there a decrease in productivity with an increase in hours or person-power?
- Which method has the least decrease in productivity?
- Which method is right for your job?

The following chapter aims to answer these questions, give guidance and establish expectations when a job is forced to accelerate. While there may be no “best” method, each of these acceleration techniques will be laid out and analyzed. This chapter will present a comparison between the methods and an overall summary of the comparisons and the types of jobs for which they would be useful.



Overtime

Overtime Snapshot:

- Overtime is a common form of acceleration.
- Increased cost because of premium pay.
- May require extra management and support to maintain steady work.
- 10% decrease in productivity for every 10 hours/week added.

Overtime is an easy way to increase the man-hours on a job because it does not involve hiring additional workers or coordinating multiple trades within the same area. The use of overtime is very flexible and can be changed on a daily basis. This is attractive for circumstances where the size of the change is unknown.

There are two most common forms of overtime:

- Sporadic or **spot overtime**, which is used to accommodate unexpected problems or to finish time-critical work.
- Scheduled or **extended overtime**, which is used to complete a project early or as an incentive to attract labor.

Spot overtime – Overtime that lasts for a limited amount of time – generally three weeks or less

Extended overtime – Overtime that lasts for periods longer than three weeks

An example of spot overtime would be to extend work hours to 10 hours a day for two days in order to complete an owner-directed change with no schedule extension. Extended overtime is used less often because it can be expensive. If the schedule will be tight, a different form of acceleration is often more attractive.

While overtime does increase the weekly man-hours on a project, it does not increase hourly productivity. Additionally, overtime is very expensive because hourly pay for the workers is generally one and a half the standard wage. Hourly productivity during periods of overtime decreases due to a few factors:

- Physical fatigue from working longer hours is the largest factor for decreasing productivity.
- A lower quality of work from extended hours and physical fatigue leads to rework.
- Absenteeism increases when workweeks are increased from a 5-day workweek.
- Additional management and support is required to keep pace with the overtime workers to limit work without direction or out of sequence work.

Quick Question: How much of an effect has been seen on projects?

Numerous studies have been done on the subject of overtime and while studies on construction projects are not always individually reliable, when compared and averaged, the numbers become more meaningful. From all of the studies observed, the overall efficiencies for fifty, sixty and seventy hours per week are 90%, 83% and 71% respectively of the standard schedule efficiency (see Figure 4). As a rough approximation when trying to predict what kind of efficiencies to expect, there is approximately a **10% decrease in efficiency for every 10 hours of week added to the work schedule**. Work will still proceed faster than without the overtime, but the return is not proportional.

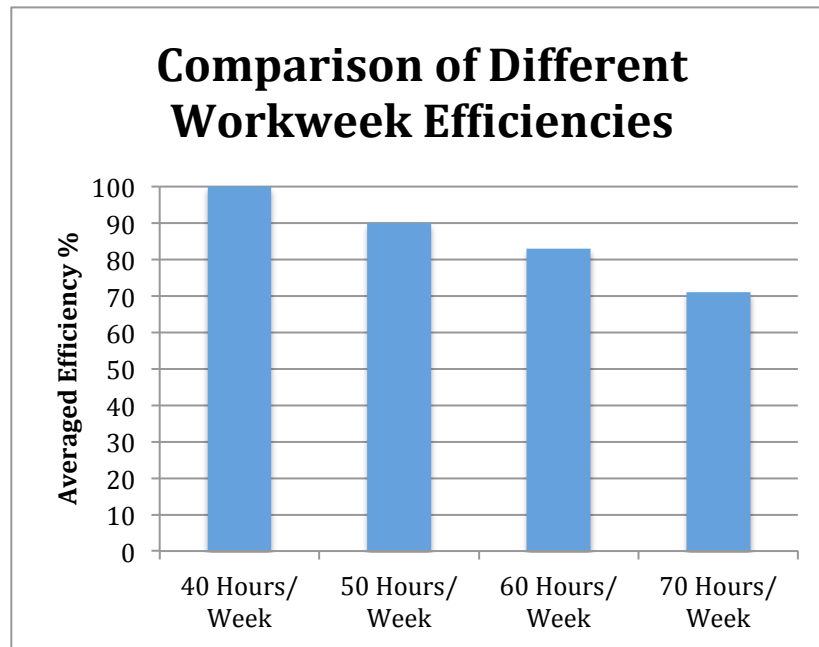


Figure 4: Overall efficiencies for different overtime work schedules. (Lee, 2007)

The graph above shows the general loss of productivity due to overtime and varies with the amount of time overtime is used. The amount of efficiency that is lost increases if overtime is used for periods extending over 8-10 weeks (see Figure 5).

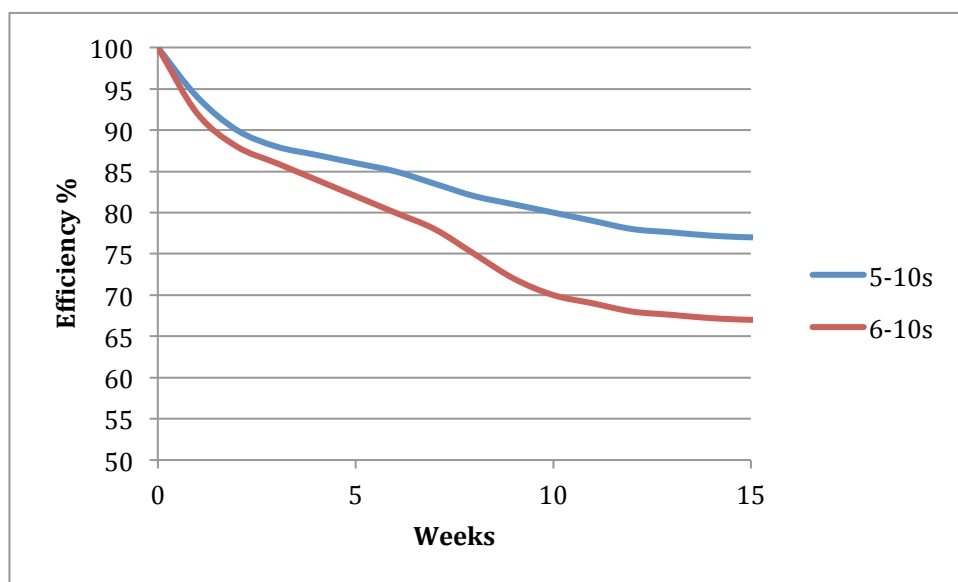


Figure 5: Change in efficiency as overtime is extended. (Lee, 2007)

Overtime is frequently used because it offers a flexible form of acceleration. This is especially true for changes requiring short bursts of increased production. It is less useful for extended periods of time because it quickly becomes costly, and the worker's productivity continues to decrease as the period of overtime extends. Overtime decreases the productivity on a project and may require additional management and support from the office staff to maintain a continuous flow of work.

Overmanning and Trade Stacking

Overmanning Snapshot:

- Overmanning involves increasing the number of workers within the same trade on a project.
- Obtains higher rates of progress without the overtime issue of fatigue.
- Decrease in productivity due to congestion and less direct supervision.

Trade Stacking Snapshot:

- Trade stacking is when multiple trades are working in the same workspace.
- Competition and tensions can occur within the trades.
- Has the same benefits and drawbacks as overmanning with congestion being the largest issue.

Overmanning and trade stacking, like overtime, are common forms of acceleration. Overmanning is generally flexible, giving the ability to add an extra worker or two to a crew without causing any major changes. It also has benefits above overtime because there is no premium pay associated with overmanning, and there is no added physical fatigue. Trade stacking also has the benefit of getting more work done in the same space at the same time, with no premium pay or added fatigue. This does not mean that overtime and trade stacking will necessarily solve all your acceleration problems. There are still issues that must be considered when trying to quantify the overall effect or estimate what that effect will be.

There are two ways to increase the number of workers on the jobsite:

- Add workers to an existing **typical size crew**.
- Increase the number of crews.

Typical size crew- the minimal amount of workers required to complete a given task in the original amount of time.

The first of these two options is more flexible because it is easier to add a worker or two to an existing crew. Additionally, you can only add a crew if the accelerated task is large enough to have more crews working at the same time. A problem with the first method, however, is that there can be complaints from changing the proportion of journeymen to helpers.

With both methods there are some drawbacks that may occur and lower the productivity rate:

- **Congestion** of workers.
- Less direct supervision for the workers.
- Additional training required familiarizing new workers with the task.
- A higher accident rate, though this may be due to congestion.
- Materials and tools being used too fast for restocking.

Congestion – crowding of workers; a function of the number of workers in a limited workspace.

These drawbacks will lower your productivity such that for each additional worker, you will not be getting the full amount of expected work from them. However, your project will proceed faster than it would have before adding that worker to the site.

Management has a large role in how much productivity will be lost due to adding additional workers. The amount of management needs to increase as the number of workers increases to be able to maintain a steady flow of

work, as well as coordinating the use of the limited space available.

By combining the conflicting data on the effects of overmanning, we are able to get a reliable picture of the overall effect (Figure 6). This will be applicable for both overmanning and trade stacking because it is measuring efficiency by the square feet per worker, which is true for multiple trades.

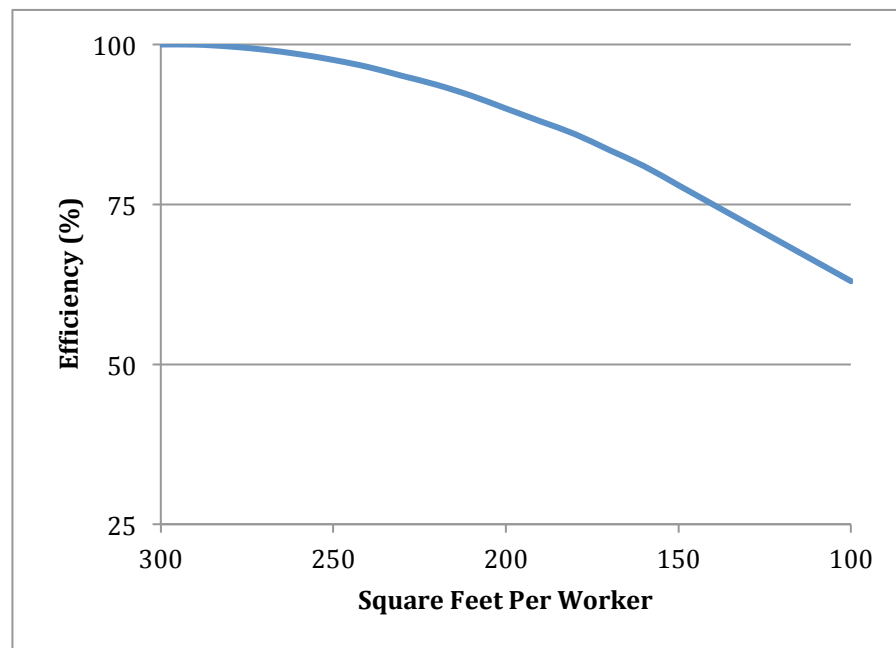


Figure 6: Change in efficiency as crowding is increased, derived from Lee, 2007.

This graph shows that between 200-300 sf/worker, there is little impact on productivity, but below that there is a rapid loss. Also, congestion is not a trivial impact and can have major consequences if the effects of crowding are not considered.

Overmanning and trade stacking are good solutions if acceleration is required and there is sufficient space to allow more people to work at the same time. Keep in mind that congestion can have a large impact on productivity. Also, management must work harder to make sure that there are sufficient amounts of supplies, tools,

materials, and a clear layout of work to ensure that workers are able to work continuously, without costly interruptions.

Shift Work

Shift Work Snapshot:

- Shift work is the least common form of acceleration because it has limited application of use.
- Generally requires no regulations regarding work hours.
- Necessitates additional management.
- Does not have the inefficiencies of overtime and congestion because there are no fatigue or crowding issues.

The third type of acceleration is shift work. Shift work involves hiring a second (or third) crew of workers to work after the first crew. The main advantages are:

- There are not the immediate fatigue factors from overtime.
- There are not the congestion factors of overmanning or trade stacking.
- The premium pay for shift work is still less than overtime pay.

It has limited use because it often requires night work, which is not allowed on many job sites. Additionally, it requires added use of supervisory and management staff, who would also have to extend their hours to keep up with production. However, shift work also has some major drawbacks, which is why it is the least common form of acceleration that is used. The main factors to consider are:

- Problems caused by working at night such as lighting, heating, sleep schedules and disruption of personal lives.
- Issues associated with changing from one shift to the next.
- Keeping supervision over several shifts and transferring management information between the shifts.
- Not flexible in term of adding short amounts of increased labor.
- Added safety problems.

These are important factors, but if there is a large project that requires work beyond a standard shift and there is the ability to perform work at night, shift work can be useful. This is especially true for extremely hot climates, where productivity at night when the temperatures are cooler is actually higher than during the day.

Figure 7 below shows the productivity losses due to the use of shift work. Using very small amounts of shift work (less than 5%) can contribute to a productivity increase. Above 5% shift work can lead to increasing productivity losses. Keep this in mind when considering the use of shift work to accelerate your project.

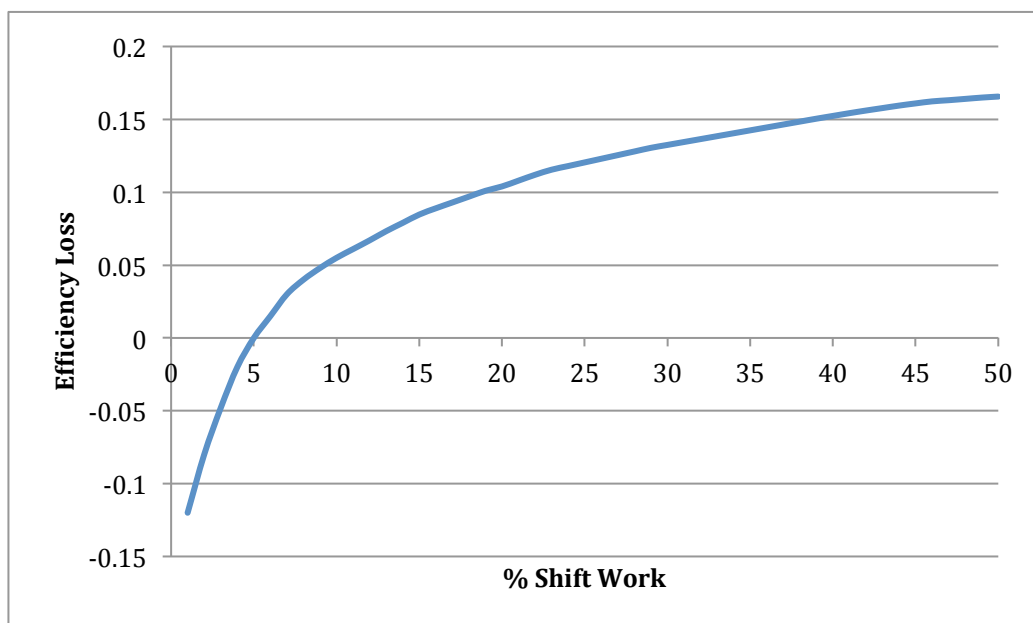


Figure 7: Effects of shift work on labor productivity. (Hanna, 2008)

In general, the productivity losses due to shift work come from supervisory, coordination and transition problems. This makes it hard to quantify the actual amount that it will affect a project and it is dependent on the organization and type of work. Shift work can be useful if there is good communication, coordination, and transition to allow one shift to seamlessly pick up where the last shift ended. The reason shift work has not been used is because its application is limited. It

practically should be used on larger projects, where shift work would be used for an extended period of time.

Acceleration: Wrapping Up

Acceleration is used on projects all the time for many different reasons to increase production speed on a site. The most common cause is to make up the time for an owner-directed change that was not granted an extension (Figure 8).

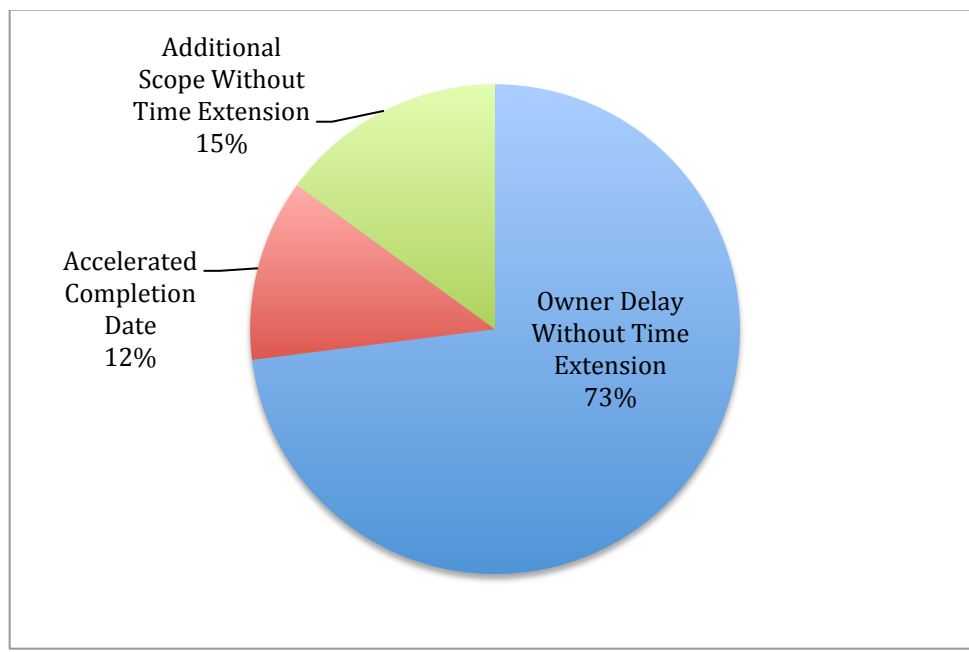


Figure 8: Causes of Acceleration, derived from Lee, 2007.

The ability to address the issues associated with acceleration, as well as to be able to choose the correct type of acceleration for each project can minimize the loss to productivity. Additionally, it is important for estimating and conflict resolution to be able to quantify the effect that acceleration will have and the associated productivity losses that it brings.

Table 1 below summarizes the main advantages and disadvantages for each type of acceleration. Each of these items will have a different effect on each individual project. These are guidelines to show the pros and cons for decision makers.

Overall Acceleration Summary			
		Advantages	Disadvantages
Overtime	Sporadic	<ul style="list-style-type: none"> • Limited impact because of short duration • Handles immediate problems quickly without future schedule changes • Very flexible 	<ul style="list-style-type: none"> • Premium pay • Requires increased management • Fatigue causes productivity losses
	Extended	<ul style="list-style-type: none"> • Decreases overall scheduled time • Attracts workers because of increased pay 	<ul style="list-style-type: none"> • Premium pay • Loss in efficiency as hours per workweek increase • Requires increased management
Overmanning, and Trade Stacking		<ul style="list-style-type: none"> • Avoids fatigue problems associated with overtime • Flexible option for acceleration 	<ul style="list-style-type: none"> • New workers to the site have to be brought up to speed • Can have productivity losses due to congestion
Shift Work		<ul style="list-style-type: none"> • Does not have the productivity losses associated with overtime or congestion • May be able to minimize the equipment rental cost if paying per day • Can give weather support if there are warm conditions during the day 	<ul style="list-style-type: none"> • Not an option for many site conditions • Difficult coordination between shifts • Requires extra management support

Table 1: Advantages and disadvantages associated with the types of acceleration, derived from Lee, 2007.

For a quantitative comparison of these methods, a lot is dependent on the site conditions. Follow the flow chart below to find which type is best for your job.

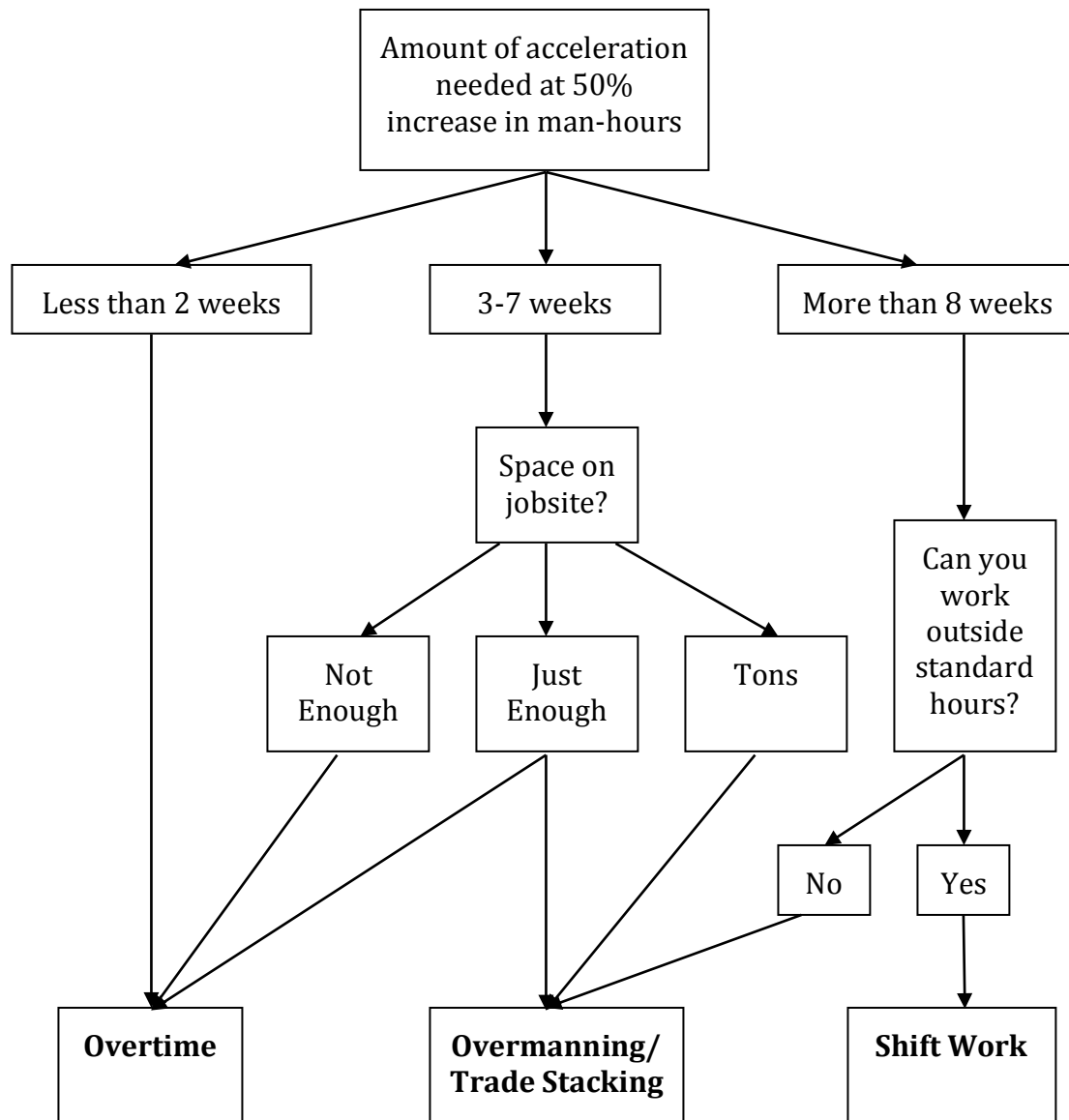
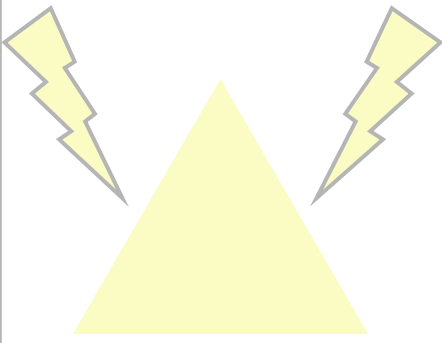


Figure 9: Flow chart for choosing acceleration type.

While this flow chart is not the only thing that should be consulted when making a decision to what type of acceleration will work for your job, it is good to look over to make sure that you are thinking about the major factors decreasing productivity like congestion and fatigue.



Weather

- Introduction
- Reasons for Productivity Loss
- Quantifying Productivity Losses
- Wrapping Up

Chapter Learning Objectives

1. Discuss how different types of weather can affect a job
2. Understand how the overall effects can vary depending on both the type of weather and the type of work
3. Quantify the potential losses in productivity

Weather: Introduction

Quick Facts:

- Weather impacts are often denied by owners and therefore should be considered in planning and estimating.
- Productivity impacts due to weather vary greatly based on type of work performed.
- Effects are regional, and so specific factors should be considered depending on the climate.

Unexpected weather conditions can cause delay, damage and changes. Obviously the effects of uncommon weather conditions can be severe. While contractors have an uncanny ability to hope for the best, it is important to prepare for normal bad weather patterns. For example, it will snow in Minneapolis, it will be unbearably hot in Tucson, and it will rain in Seattle. The problem is that there are timelines and schedules that must be met, so how does an excusable weather event affect the job?

There are important factors to consider when trying to measure the impact weather may have on your project:

- Type of work (manual or equipment, indoors or outdoors)
- Type of weather (hot, cold, rain, humidity)
- Length of weather event (all season or short burst)
- Severity of weather (extreme heat or cold)

It is especially important to keep in mind the health and safety of all workers. Do not subject workers to unnecessarily dangerous working conditions, and this includes extreme heat and cold.

Reasons for Productivity Loss

Productivity losses due to weather are affected by:

- The worker's physical condition.
- Site and material conditions.
- Motivation of the worker.

The worker's physical condition is the most obvious of the three productivity factors. If temperatures are extreme, the physical abilities of workers are limited. The site conditions are impacted when, for example there is unexpected rain showers, or the ground freezes. In both of these conditions, earthwork would be impacted. Finally, the motivation of the workers declines when the weather is not comfortable.

	Cold Weather	Hot Weather	Rain
Productivity Losses Due To:	<ul style="list-style-type: none">• Inconvenience of weather protection (gloves, extra layers)• Hypothermia concerns with workers sweating then cooling down rapidly	<ul style="list-style-type: none">• Rapid fatigue• Frequent breaks are necessary• Loss in motivation	<ul style="list-style-type: none">• Materials, equipment and soil gets wet• Limited visibility• Slip hazard

Table 2: Reasons for productivity loss due to hot, cold, or wet weather, derived from Lee, 2007 Table 6.6.1.

There are obvious effects of weather, but there are also some more subtle effects to keep in mind that can be harder to quantify. These are the losses in productivity due to stopped work and causing delays, both which have productivity losses associated with starting and stopping work and a loss of job rhythm.

Quantifying Productivity Losses due to Weather

There is a lot of research on quantifying the effects of weather on workers' productivity. Remember that there are a lot of different factors that weather can have beyond just worker's efficiency, such as the ability to work outside in the rain and equipment limitations. Also, not only temperature, but also humidity and wind have productivity factors associated with them. As an overall reference, Figure 10 below shows the *efficiency* as a function of temperature.

As stated previously in this field guide, productivity is the number of units out over the number of worker-hours put in. Efficiency on the other hand is the actual output over the standard output. For example, if at ideal conditions a worker could produce 100 units in an 8 hours, but he only produced 65 units that day because conditions were not ideal, his efficiency would be 0.65. In this same scenario, the productivity on this task will have dropped from 12.5 units/hour to 8.1 units/hour. Efficiency is related to productivity because if you have lower efficiency, your productivity will be lower as well.

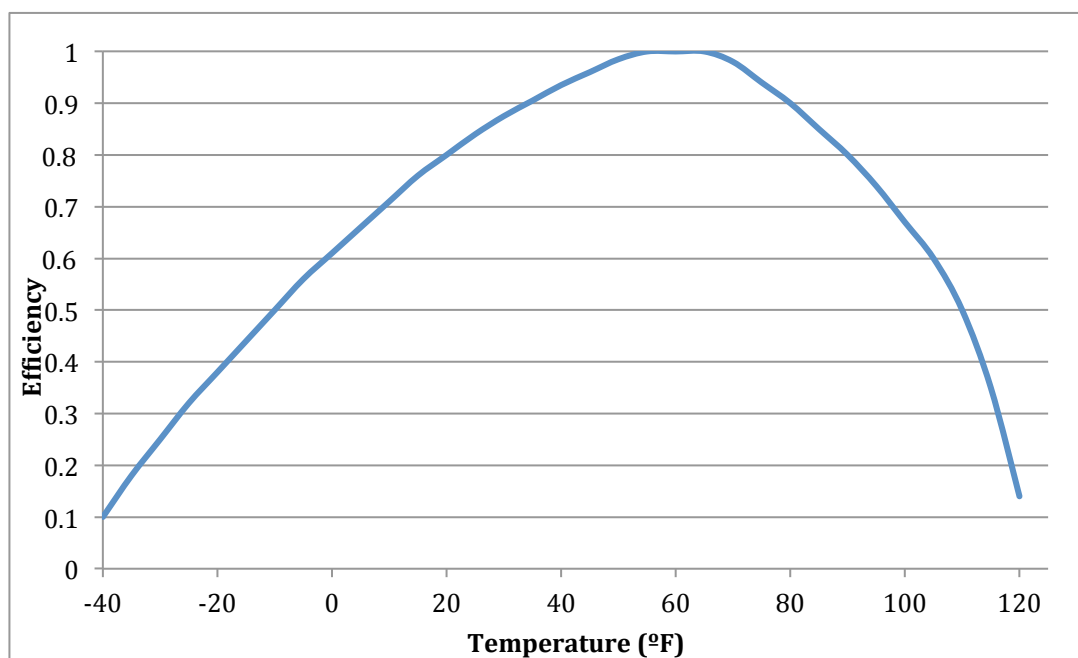


Figure 10: Overall Productivity Impact from Temperature, derived from Lee, 2007, Figure 6.6.22

It is clear that there is a more rapid impact for the highest temperatures, but it is important to note that there is a range of 70°F where efficiency will be at or above 75%. With extreme heat and cold there is a dramatic effect on the overall productivity, and in these cases worker's safety should be considered.

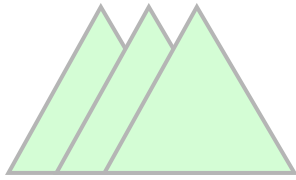
Other Important Factors when Quantifying Productivity Losses

- Humidity
- Wind and wind chill temperatures
- Sun exposure
- Type of work being performed (heavy, light, equipment, etc)
- Overall site conditions

Weather: Wrapping Up

Weather can have a considerable effect on a construction project, but it is important to remember that the only recoverable portion is for unforeseeable weather events or those that are specifically excluded from the contract. It does not count as a delay if it rains during a San Francisco winter, or if there are high temperatures in a New Mexico summer. Weather should be taken into account during estimating and scheduling of a project.

Unforeseeable events that are unusual and unexpected can be recoverable, and it is important to account for not only the direct delays, but also the indirect productivity losses associated with starting and stopping. Also, for extended periods of heat, cold and rain, it may not be an option to shut down completely and work will have to continue at a slower rate. It is important to be able to quantify the productivity loss due to a lower efficiency of the workers. This will help you quantify the damages owed to the contractor during unusual weather events.



Learning Curve

- Introduction
- Uses, Impact and Analysis
- Wrapping Up

Chapter Learning Objectives

1. Understand what the learning curve is and how it impacts a project
2. Use the learning curve to estimate the number of labor-hours required to complete a repetitive task

Learning Curve: Introduction

Quick Facts:

- For all repetitive tasks there is an increase in efficiency as the number of repetitions increases.
- The type of activity or trade will affect how much efficiency increase can be seen in later repetitions.
- Learning curve effects may already be included in the quantification of the impacts of overtime, overmanning and shift work.
- Re-estimate learning curve effects when a change occurs to estimate the remaining duration.

The learning curve effect in and of itself is not a cause of productivity losses (or gains) like the effects that have been presented in earlier chapters because it is an inherent characteristic of repetitive work, not something that happens that causes losses or gains. It is still important to understand and be able to quantify though because it is one of the most basic mechanisms that changes productivity on your job.

The learning curve shows how a repetitive process will speed up over time, due to a worker “learning” a task. For example, the first time you put together IKEA furniture, it takes forever. You don’t know what the little pictures are trying to show you, or what all the pieces are for. But by the 5th or 6th piece, it’s a breeze. You could write the manual on that piece of furniture, and you aren’t making the same mistakes you did the first time. This is really true for any process in your life. It can take a toddler minutes to button up a shirt, while an adult can do it in seconds. The same idea is true for construction processes.

Whenever there are repetitive processes, the time it takes to do consecutive activities tends to decrease. There are two principal phases for this improvement according to the Economic Committee for Europe (United Nations, 1965):

1. Operation-learning phase: learning the basic way the task is to be performed which is broken up into the initial organization or planning of the work, and the real “hands on” learning phase.
2. Routine-acquiring phase: improvement as the worker gets more and more comfortable with the task and identifies small changes in the work method and organization that can streamline the activity.

During the operations-learning phase, there is an initial learning of the job to be performed and an organization of how this will carry out in the field. It is during the routine-acquiring phase that the real gains in efficiency are seen for many reasons. Some of these are:

- Greater familiarity with the task.
- More effective and efficient use of the tools and equipment.
- Standardization of the procedure.
- Better coordination and teamwork within the crew.

These will significantly lower the amount of time it takes to complete a task and should be taken into account when estimating a project.

Uses, Impact and Analysis

Now that you understand why the learning curve is important, you might be asking how much of an impact it can have? Figure 11 shows the standard, straight-line learning curve. While there are many different calculations for the learning curve, the straight-line method is the most widely used and is a fairly good predictor. Also, because it is widely used, there is considerable acceptance in dispute resolution settings.

There are some disadvantages though because it is very simplified and assumes that the “learning rate” is constant throughout an operation. It is also important to remember that the rate will be dependent on the trade and the type of activity being performed. Below is a straight-line learning curve that is useful for general

activities, but is not trade or task specific, so the rates of learning should be specific to the analyzed trade.

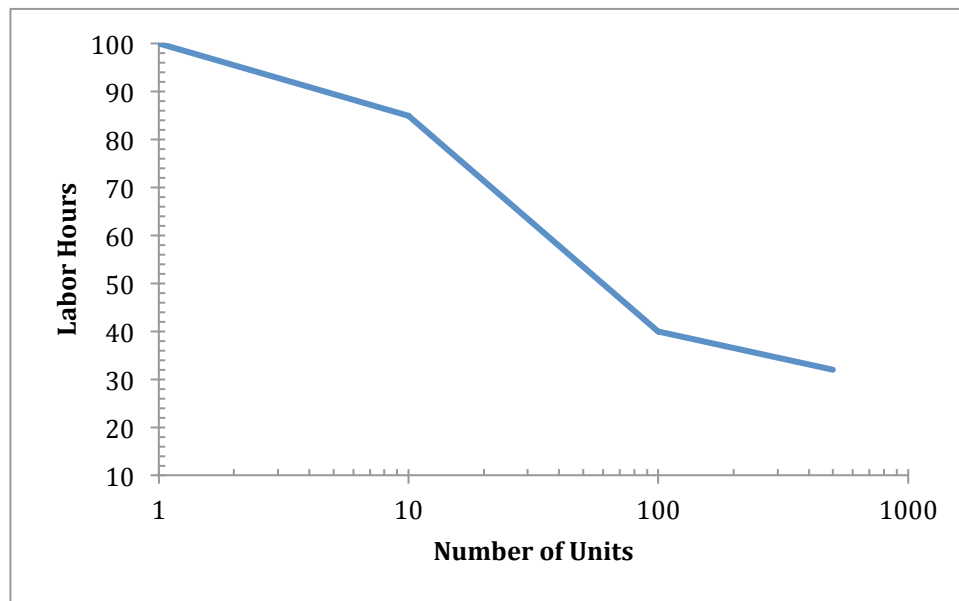


Figure 11: Straight-line learning curve, derived from Lee, 2007, Figure 6.7.17.

This figure shows three different rates. One for the first ten units, learning is beginning and there is a relatively slow decrease in labor hours per unit because the work is still new. A unit can be any part of the work you are looking at from a door to an entire floor of a multi-story building. For units 10-100 there is a faster learning where workers are becoming comfortable with the activity and work is going well, so the labor hours per unit are decreasing rapidly. Above unit 100, the learning rate starts to slow again as you reach the lowest possible time it would take to complete an activity.

The slope of the line at each part is the learning rate, and can be changed depending on the type of work being done. There are certain tasks with an incredibly high rate, which will decrease the amount of hours per unit faster. Other tasks have very slow rates because of their complexity, or their characteristics.

There can also be equipment limitations where the time it takes to complete a task is limited by how long it take the equipment to complete the task.

Wrapping Up

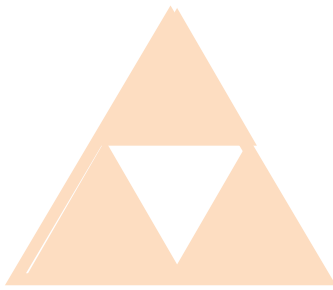
While the learning curve itself is not a cause of productivity gains or losses, it is important to keep in mind that a worker's hours per unit of work may decrease significantly as he or she does more units of that work. This is important to remember during estimating, and when quantifying the duration of changes throughout the project.

Also, when applying the learning curve to estimate the anticipated duration, it is important to keep in mind the type of task being performed and the limit on the minimum time the task can take. Tasks can be time-limited if they:

- Are complex and intricate.
- Require special inspections.
- Rely on a piece of specific equipment.
- Already are performed at the maximum rate.

The learning curve is a good tool to show the decrease in time per unit through multiple repetitions. This occurs because initially the work is slow and gets faster, not because the work begins at full efficiency and goes up from there. This is an important distinction when going forward.

When estimating the amount of time to schedule for repetitive tasks, keep in mind that the first few units of the work may be significantly slower than the subsequent units. The rate of learning, however, must be adjusted to the specific type of work being performed.



Combining Multiple Factors

- Introduction
- Key Points
- Leonard's Curve
- Ibbs's Curve
- Wrapping Up

Chapter Learning Objectives

1. Understand when it is necessary to combine multiple impacts
2. Learn to check for interrelationships and dependencies between factors
3. Discuss the limitations of calculating the compounded effects



Multiple Factors: Introduction

These discrete methods are very useful for calculating the effect that one factor can have on your job. Often these events do not occur by themselves. It can still be possible to separate the effects as much as possible to calculate the losses from each. There are some important key points to remember when doing these calculations, but it can be done with some degree of reliability.

Other times events are so interdependent that they cannot be separated to calculate individually. In these cases you either have to estimate as accurately as possible the losses attributed to each occurrence, or use global methods that are described in Chapter Nine. These methods are less reliable, but are still often used in practice. When it is not possible to identify each factor and their individual contributions to productivity loss, these methods can help at least develop roughly credible quantified estimates.

This chapter will give you a greater perspective on how to conservatively combine multiple productivity factors and thus present a more credible change request. The total amount of change your site experiences can have a large impact on your productivity. The Leonard and Ibbs's Curves show reasonable estimates based on industry research to allow you to have an idea of what productivity losses your site could be experiencing if there are multiple changes or change orders.

Leonard's Curves

Many research studies have been conducted on the subject of cumulative change over the years. One of the first was by Charles Leonard, whose master's thesis is one of the earliest and most widely-cited publication on the subject of quantitative impact of change. In that study he collected data from fifty-seven projects and organized it into electrical/mechanical work and civil/architectural work.

Percent change was measured by the ratio of changed order labor-hours and actual contract labor hours, with actual contract hours being the project's total labor hours minus the change order labor hours themselves minus any contractor mistakes.

This resulted in two different graphs, one of electrical/mechanical work and the other for civil/architectural contracts. Each graph had three linear curves, one representing projects substantially affected only by change orders (Type 1) and the other two curves representing project substantially impacted by change orders + one major cause of delay (Type 2) and change orders + two or more major causes of delay (Type 3).

These complicating factors include:

- Inadequate scheduling and coordination
- Acceleration
- Change in work sequence
- Late supply of information, equipment or materials
- Increased complexity of work
- Ripple-effect of change orders issued

Two key findings were that large amounts of change create large amounts of productivity loss and change orders can cause productivity loss on both the change work and the base contract work. (See Figures 12 and 13)

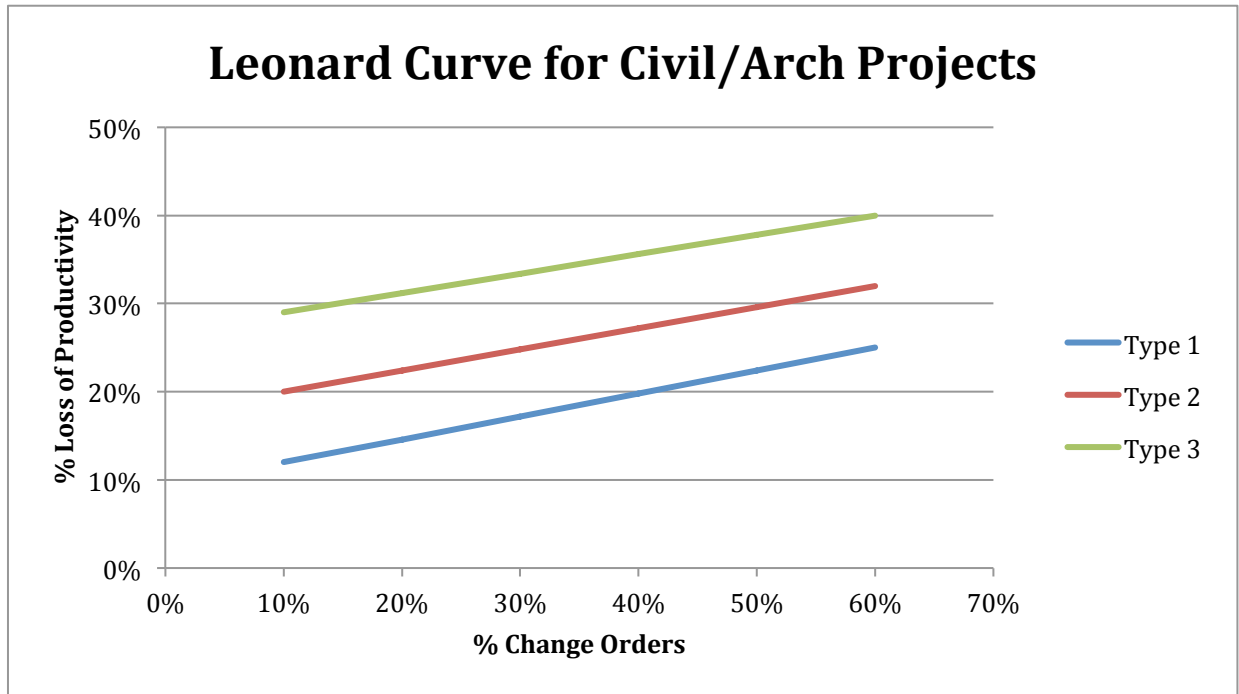


Figure 12: Leonard's Curve for civil and architectural projects showing the loss in productivity as a function of the % change orders.

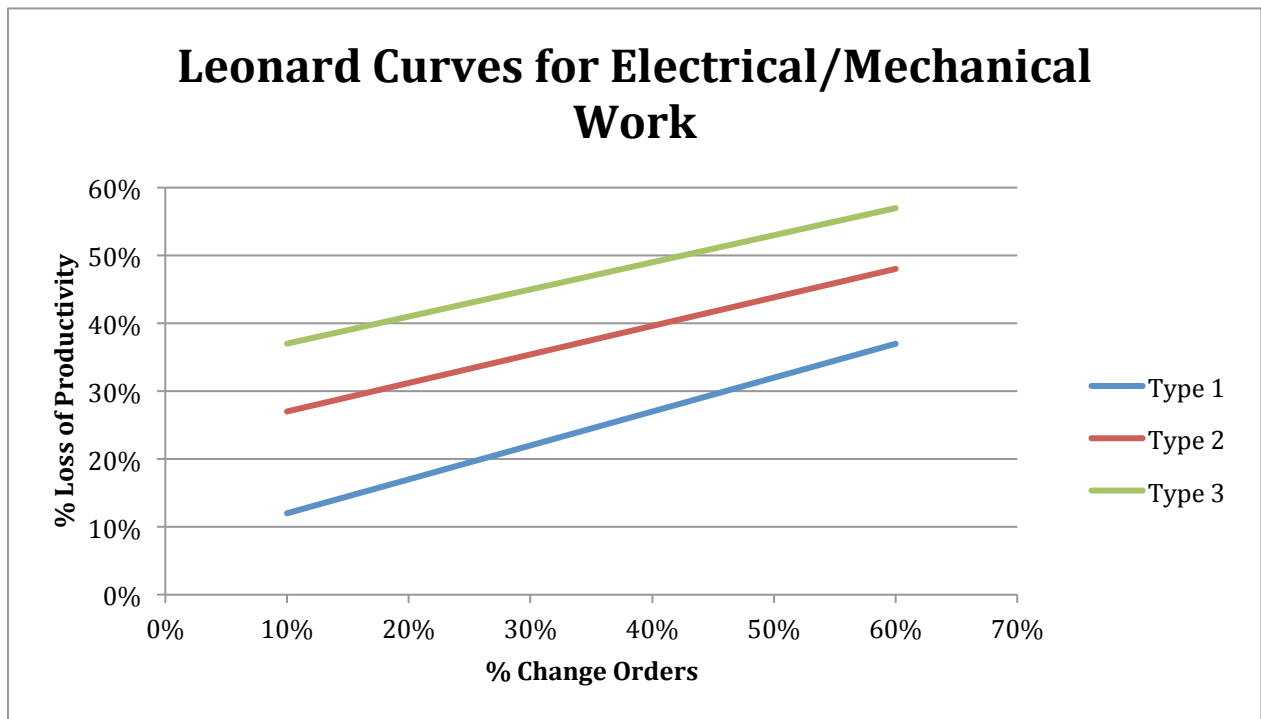


Figure 13: Leonard's Curve for electrical and mechanical work showing the loss in productivity as a function of the % change orders.

Ibbs's Curves

Ibbs improved on Leonard's work, collecting data from 169 large, diverse projects. Projects were larger, included both good and bad experiences, came from twelve different countries and included design phase information. Total installed costs for these projects ranged from \$3.2 million to \$15 billion, with most projects in the \$20 million to \$100 million dollars range.

Different delivery systems, different industry sectors, and grassroots and revamp projects were examined. Telephone and in person follow-up interviews were conducted to verify that the projects were a representative sample of projects. Ibbs's analysis used projects more representative of the industry (See Figure 14).

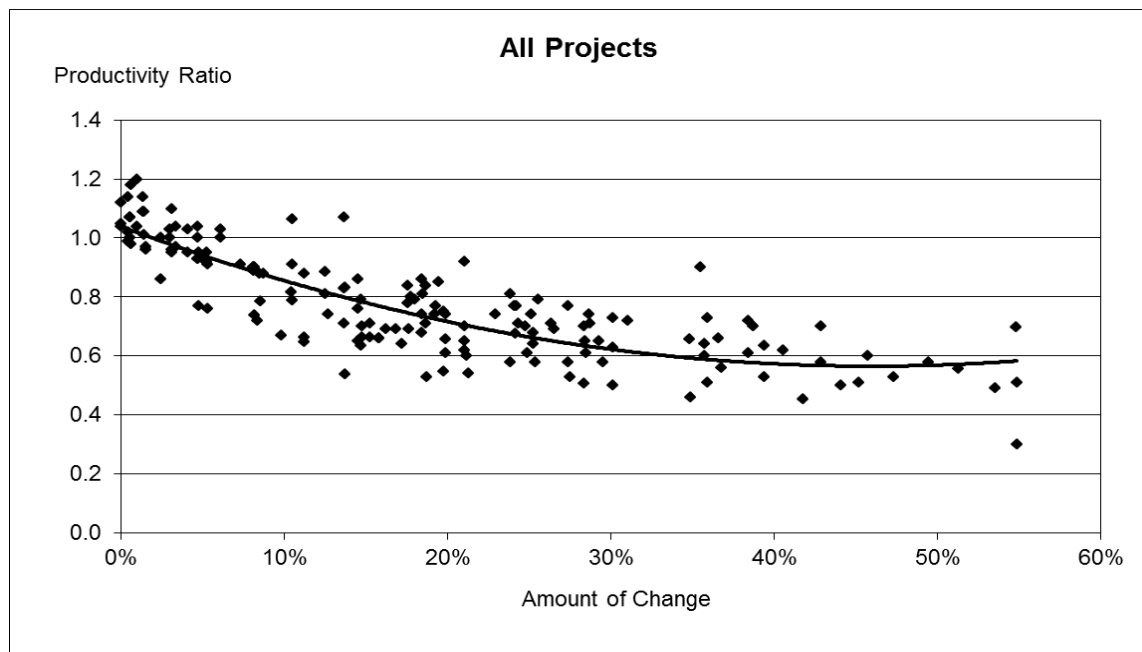


Figure 14: Ibbs's Curve showing the productivity ratio as a function of the amount of change experienced.

Ibbs also studied the effect that change timing has on productivity. Generally speaking, projects that had most of their change late in the project had lower levels of productivity than projects with earlier change (See Figure 15).

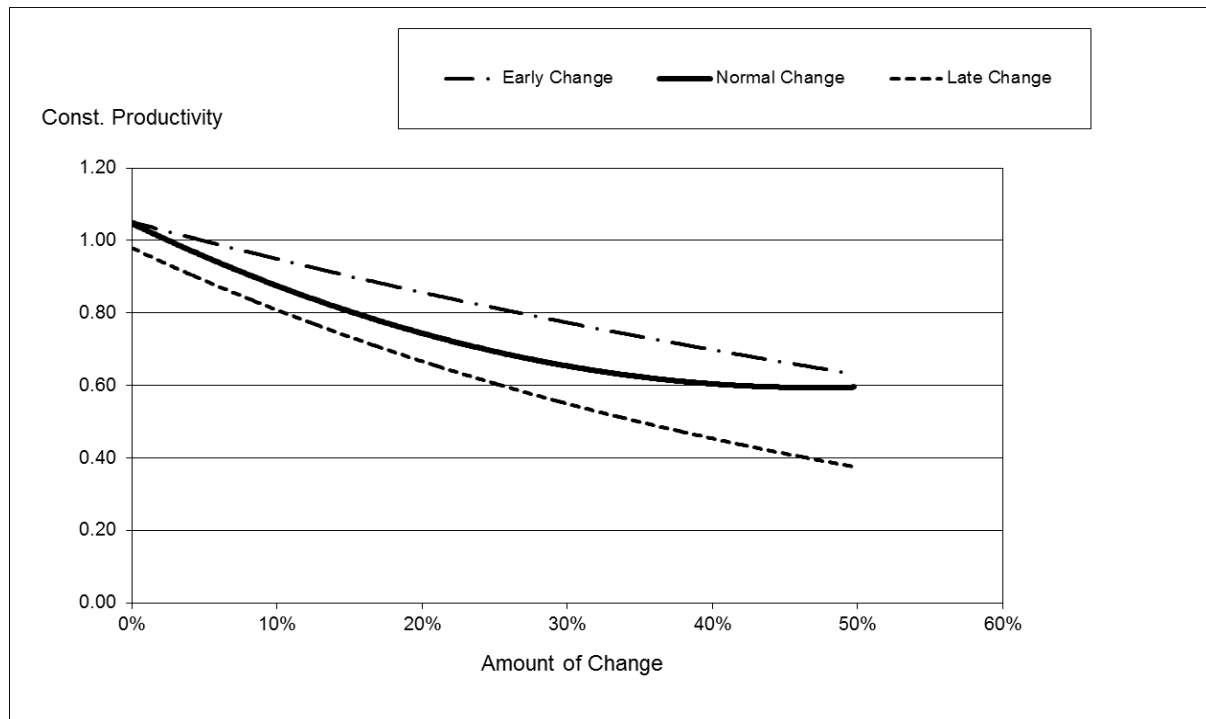


Figure 15: Ibbs's Curve showing the productivity as a function of the amount of change based on timing of the change in the schedule.

These graphs are useful for measuring the impact of change, regardless of its type, and have been accepted in mediations, arbitrations and litigation.

Key Points

It is common to have multiple productivity factors affecting your job at the same time. For example, during a period of overtime it is possible to have negative weather effects. Each of these factors has an individual contribution to productivity loss, but the combined effect may not be as high as the sum of the two losses individually, or it could be greater. There may be interrelationships and

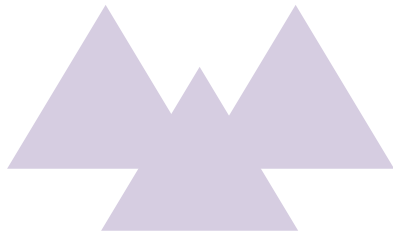
dependencies that should be taken into account when quantifying the losses. When combining multiple factors, it is very important to check the interrelationships and dependencies.

Double-counting productivity losses can happen if one factor is a result of another. This can be avoided if cause-effect relationships are checked. Cause maps can help identify these relationships. If one factor is a result of the other, then the losses from the cause should be counted.

Also, if you have multiple changes occurring on your site, there can be additional productivity losses that are attributable to the percent change your job has experienced. This is dependent on many factors, but the Leonard and Ibbs's Curves can be helpful in estimating these losses. The timing of the changes will also help dictate the total percent productivity lost.

Combining the effects of multiple sources is subjective and requires careful analysis. It is important to identify what the losses in the original estimation are due to. The total amount of change that your site experiences can lead to a major loss in productivity, especially if those changes occur late in the schedule.





Cumulative Methods

- Introduction
- Total Cost Method
- Jury Verdict Method
- Actual Cost Method
- Measured Mile Analysis
- Industry Indices and Studies
- Choosing the Best Method
- Comparison of the Methods
- Wrapping Up

Chapter Learning Objectives

1. Understand why cumulative methods are developed
2. Describe different types of cumulative methods
3. Discuss which methods are the best to use



Cumulative Method: Introduction

Quick Facts:

- Cumulative method captures collective productivity losses from multiple changes.
- Does not distinguish what losses are associated with specific factors.
- Generally used when it is not feasible to separate individual factors.

There are many different forms of cumulative methods that can be used to quantify the losses and damages that are due to multiple different changes. The different methods that will be explained in this chapter are, in order from most uncertain to most accurate:

- Jury verdict method
- Total cost method
- Industry indices and new studies
- Measured mile analysis
- Actual cost method

While these are not as quantitative and exact as the direct methods talked about in the previous chapters, it is not always possible to determine what losses are the causes of a particular change. In this case, it is still necessary to be able to quantify the damages. These are the methods that the industry has developed to answer this issue.

This chapter will go through a brief description of each of the different cumulative methods. It is important to be familiar with each of these methods in case you are asked to quantify your losses if a project was ever taken to claim. This is by no means a fully intensive review, but more an introduction to the common methods available.

Jury Verdict Method

Jury Verdict Snapshot:

- Often uses the total cost method as a starting point.
- Jury decides the amount of the total damages due to the contractor.
- Generally results in a more conservative estimate of the lost productivity.

The jury verdict method is used when damages cannot accurately be determined by any other method, but damages are clearly there. The jury is allowed to make the award, but three requirements must be satisfied. These requirements are:

- Clear proof of injury to the contractor.
- Absence of a more reliable method.
- Sufficient evidence for a reasonable estimate of the damages.

The amount determined is generally based on the evidence presented during the hearings. The jury is able to use whatever methods they deem reasonable, and often results in a more conservative estimate of the lost productivity. While this is not the contractor's first choice, it is still a viable option.

Total Cost Method

Total Cost Method Snapshot:

- Simplest and easiest of all the available methods.
- Appealing to contractors because it assumes they did everything correct.
- Courts are reluctant to accept this method.
- Is rarely used, but sometimes the only path for the contractor.

The total cost method calculates damages by subtracting the bid amount from the total actual costs. For example:

Contractor spends	12, 145 labor-hours completing a task
Labor rate is	\$31.88/hour
Total cost	\$387, 182
Markup @ 20%	\$ 77, 437
Total value	\$464, 619
Contract amount	\$310, 000
Claimed amount using total cost	\$154, 619

This method is straightforward and quick to calculate, but has three major assumptions:

- The contractor did everything right.
- The bid estimate is correct.
- All extra costs are the fault of the owner.

These are large assumptions that can be very difficult to prove. It is important to remember that if any fault of the contractor is found, the claim can be dismissed. While courts are reluctant to accept this method, they allow it if four requirements are met and proven (Servidone, 1987). These requirements are:

- Impracticality of proving actual losses accurately and directly.
- Reasonable and realistic bid estimate.
- Reasonable actual costs.
- Contractor has no responsibility for cost overrun.

These requirements can be hard to prove, but it is still possible to argue this method successfully. Consider the total cost method if damages cannot be determined on a discrete basis, when there is not enough data to be able to assign costs to specific changes, or when there is no similar projects to compare your project.

It is also possible to use the modified total cost method to quantify a claim. This method is the same as the one described above, except the contractor reduces the

amount claimed in order to more fairly represent the damages. This is more likely to be accepted by the courts, but the same four requirements still need to be satisfied. Using the same example above, but adjusting the claim:

Contractor spends	12,145 labor-hrs.
Hourly rate	\$31.88 / hour
Total cost	\$387,182
Markup @ 20%	\$ 77,437
Total Value	\$464,619
Original contract	\$310,000
Difference	\$154,619
Bid mistakes	-\$10,000
Field mismanagement	-\$10,000
Paid Change orders	-\$10,000
Modified Claim Amount	\$124,619

The modified total cost method is very similar to the total cost method above, but is more realistic because it removes the assumption that the contractor did everything correctly. It is slightly more work, but also more realistic. Also, there is a greater chance of compensation because it has a more complete picture of the changes that occurred.

Industry Indices and Studies

Industry Indices and Studies Snapshot:

- Uses industry research studies and statistics to calculate the amount of impact a change has on productivity.
- Contractors and owners have developed different manuals to calculate the amount of productivity losses due to different affecting factors.
- Is limited in recognizing interdependencies between factors and applying multiple factors to the same work.

Different manuals have been created to allow contractors and owner to calculate the anticipated productivity losses due to different factors such as morale, trade stacking, fatigue, and weather. These are only a small subset of the different factors presented, but they show you the range of those presented. Figure 16 shows an example of some of the productivity factors that can have an effect on the project. These values are from the MCAA (Mechanical Contractors Association of America) manual from 1994, which has been one of the more popular sources of productivity information.

Factor	Level of Condition		
	Minor	Average	Severe
1. Stacking of Trades	10%	20%	30%
2. Morale & Attitude	5%	15%	30%
3. Reassignment of Manpower	5%	10%	15%
4. Crew Size Inefficiency	10%	20%	30%
5. Concurrent Operations	5%	15%	25%
6. Dilution of Supervision	10%	15%	25%
7. Learning Curve	5%	15%	30%
8. Errors & Omissions	1%	3%	6%
9. Beneficial Occupancy	15%	25%	40%
10. Joint Occupancy	5%	12%	20%
11. Site Access	5%	12%	30%
12. Logistics	10%	25%	50%
13. Fatigue	8%	10%	12%
14. Ripple	10%	15%	20%
15. Overtime	10%	15%	20%
16. Season & Weather Change	10%	20%	30%

Figure 16: MCAA Factors Affecting Productivity and Range of Losses, derived from Lee, 2007, Figure 7.2.5.

While Figure 16 is just an example of some of the factors that can be seen in one of these manuals, it clearly shows both the advantages and disadvantages of this method. The main advantages are:

- Clear and concise data that is easy to use and easy to apply.
- Data has been agreed upon by a group of experienced industry professionals.
- No period of unimpacted work is required.
- Multiple factors can be applied to the productivity if the effects are combined correctly.

There are also a number of disadvantages to using MCAA factors:

- Quantified impact data is developed subjectively.
- Additional subjectivity is required by users in determining the level of the condition; e.g. severe versus average is not defined by MCAA.
- Interdependencies between factors must be considered when applying multiple losses to the same work; e.g. site access versus logistics.
- Identifying the affected period of work can be difficult.

Even with these disadvantages, the industry indices have been used successfully to measure productivity losses. As explained before, conservative estimates generally yield more successful results than aggressive estimates. Use industry estimates when estimating productivity losses, but don't rely on them alone without considering other factors.

Measured Mile Analysis

Measured Mile Analysis Snapshot:

- Compares impacted productivity to unimpacted productivity.
- More reliable than most traditional methods.
- Requires sufficient unimpacted data that eliminates other factors.

Measured mile analysis compares the productivity during the period or section of work impacted by changes to the productivity during a time when there were no

changes. By finding the differences between these two productivity rates and then multiplying the result by the number of units affected by change, it is possible to calculate the total amount of loss of productivity. There are five pieces of information that are necessary to be able to use this method:

- Scope of the work that was disrupted by the changes.
- A period of time where the work was not impacted.
- Productivity during the time when the work was not impacted.
- A period of time when the work was impacted.
- Productivity during the impacted period.

The main advantage of the measured mile analysis is that it does not assume that the bid was correct. Courts prefer this method because it is more scientific and reliable than some of the previous methods.

There are disadvantages with the measured mile analysis. The largest weakness is that it can be difficult to find a period of unimpacted work long enough to calculate a reliable productivity rate. Also, to be able to attribute the productivity loss to one occurrence, you need to remove all other factors that could have affected the work. This can be difficult, as often times there is more than one factor and more than one party that is changing the work conditions. Finally, it is important to be able to define the type of work that is actually being calculated, and it can be hard to create a definable scope that is neither too general nor too detailed.

See table 3 for measured mile principles.

Measured Mile Principles²

1. Selection of the measured mile analyst.
 - a. Use impartial, experienced, knowledgeable experts.
 - b. Someone who understands both construction cost accounting and construction work methods.
 - c. Review the entire project record. Interview the project personnel, including field personnel. Review pertinent documentation, obtain clear understanding of the issues in dispute.
2. Selection of the impacted period.
 - a. Graphically plot daily, weekly, monthly productivity over time to identify periods of disruption.
 - b. Consider use of statistical methods to select impacted and unimpacted periods objectively.
 - c. Compute productivity, not production data.
 - d. At the minimum, make an effort to demonstrate cause-and-effect between the change(s) and the consequence(s).
 - i. Ideally, prove what the causes of LOP were. If unable to prove, demonstrate and explain to a reasonable degree.
 - ii. Investigate the timing of the purported disruptions and their alleged consequences.
 - e. Make adjustments for non-compensable changes and contractor-caused problems in the impacted period.
 - f. Consider developing categories of “impact severity” rather than one general category.
3. Selection of the measured mile period.
 - a. Select a reference period for a narrow spectrum of similar work.
 - i. Select a period that as similar to the disrupted period as available.
 - ii. Use quantity of work per labor-hour as a measure of productivity if possible; if not, resort to quantity of work per % project complete or quantity of work per \$ spent.
 - iii. Consider the physical character and amount of the work.
 - iv. Consider the means and methods, weather conditions, work hours, project schedule, site logistics, management and supervision, trades, etc. used to perform the work.
 - v. Consider the administrative and managerial aspects governing the work; e.g. supervisory ratios, number of and time spent processing Shop Drawings, RFIs, and Change Orders.
 - vi. Select workers with reasonably similar skill, knowledge and effort. The same labor pool is desirable.
 - vii. Separate the loss of productivity by labor trade if possible.
 - viii. Use owner-collected data if available.
 - b. Confirm that the reference period has “unhindered” productivity. Both for the contractor and any subcontractors or suppliers.

² From a paper to be published in the *Journal of Legal Affairs and Dispute Resolution*.

- i. Make adjustments if there are contractor-caused hindrances to adjust the reference period.
 - ii. Be prepared to explain those adjustments with solid reasoning, not just assertions.
 - iii. Conversion factors, perhaps derived from authoritative estimating sources, may be needed to compensate for differences between unimpacted and impacted work.
 - c. If no measured mile productivity data available on disputed project, use other information sources.
 - i. Published industry estimating guides.
 - ii. Other projects built by this contractor or by similar contractors.
 - iii. \$ per % complete, Earned value rates.
 - iv. Baseline Productivity analysis.
 - 1. Make adjustments as necessary to baseline reference period to develop true unimpacted baseline productivity rate.
- 4. Calculate the loss of productivity
 - a. Test the integrity of the underlying productivity, change, progress, etc. data.
 - b. Apply LOP factors to just the time period and labor trade disrupted.
 - c. Adjust for learning curve productivity factors in the early stages of a project.
 - d. Adjust for additional labor-hours already paid for in change orders.
 - e. Exclude any loss which is not recoverable under the contract's terms, including contractor's own problems.
 - f. Look for several different ways to compute a measured mile from the instant project.
 - i. Report the results using those different ways and bracket them into a high-low range.
 - g. Consider other reference sources.
 - i. Other projects by this contractor, other projects by other contractors.
 - ii. Other decisions by this court or board.
 - h. Be conservative.
 - i. Apply the LOP factor to just the crews and the time period involved.
 - i. Check the mathematics: don't present results that strain credibility, such as a measured mile analysis that claims more damages than a total cost claim.
- 5. Present the analysis clearly.
 - a. Explain the cause-and-effect.
 - b. Use more than broad, unsubstantiated statements such as based on "my experience".
 - c. Focus on key points, not minutia.
 - d. Include photographs, other graphic aids, correspondence, job diaries, etc.
 - e. Corroborate with other methods such as modified total cost, industry guidelines.
 - f. Rehearse before presenting. Anticipate questions and prepare answers.
 - g. Tell the truth.

Table 3: Measured Mile Principles

Baseline Productivity Analysis

A new method has been developed, the Baseline Productivity Analysis, because of the disadvantages of measured mile. Both methods compare the impacted to the unimpacted productivity. Instead of requiring a period of unimpacted work, a baseline productivity is calculated. The baseline period is the period of time during which the contractor performs his best productivity even if there are changes in that portion of the work. The amount of time that is used to create this productivity is approximately 10% of the work days. The baseline period is not necessarily consecutive days, but is the days when the contractor reaches his best production.

The baseline productivity analysis has the same benefits as the measured mile analysis, with the additional advantage of not requiring a continuous unimpacted time period.

There are some disadvantages though. They are:

- The baseline is according to the best daily output, not the best daily productivity.
- The 10% requirement for the baseline sample size is arbitrary and not based upon scientific principles.
- The median of the baseline productivities is used, not the average, and so this can be inconsistent.
- The baseline may still have owner-caused changes in it, so the contractor may be sacrificing some legitimate claims.

It is important to not that there are many other variations of the measured mile analysis. The two presented here are straightforward and relatively simple to use, but if a more complex solution is required, there is much literature that can help.

Actual Cost Method

Actual Cost Method Snapshot:

- Requires detailed cost records.
- Courts prefer this method because of its accuracy and dependability.
- Often not practical to maintain the sufficient records required.

When records with sufficient detail are kept, contractors are able to go through line by line and quantify the damages that are caused by each change. This allows the contractor to itemize and total the cost of each piece of equipment, each labor hour and each piece of material that is associated with each change. This is very reliable and preferred by courts because it is concrete and quantifiable. The problem with this method is that it requires meticulous record keeping, which is often not practical, and sometimes not possible.

The actual cost method is by far the most labor intensive because it requires detailed records of every item that is being claimed, but it is also the most accurate because there is no estimation or assumptions.

Comparison of the Methods

While each of these methods has its own advantages and disadvantages when applied to a project, they can be qualitatively compared to each other. Figure 17 below shows a qualitative comparison for the various methods in terms of:

- Uncertainty
- Effort and expertise required to use the method
- Amount of project documentation

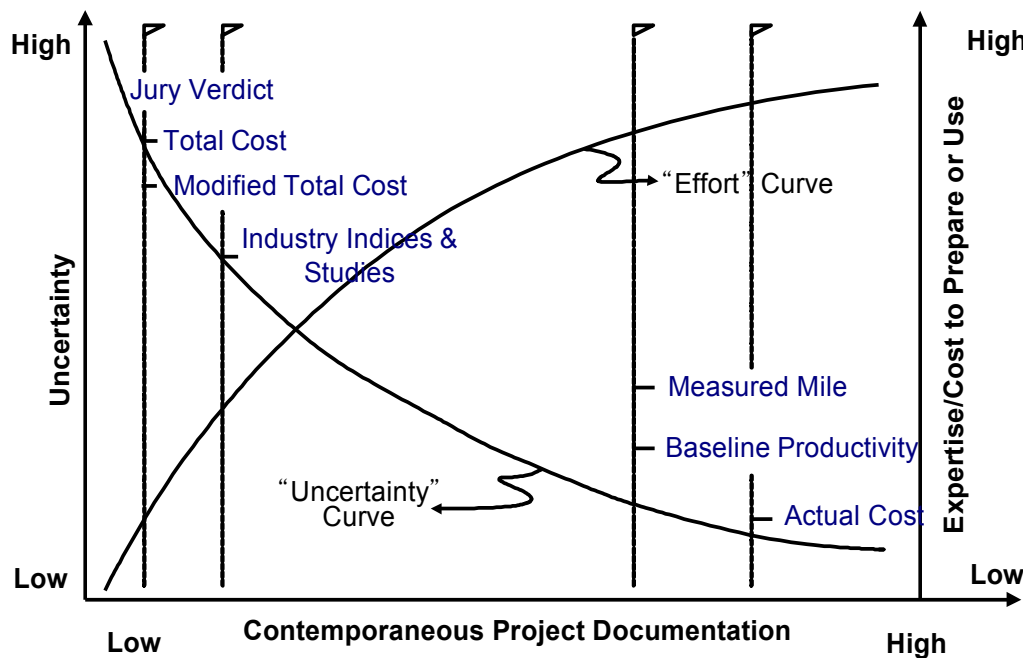


Figure 17: Comparison of Cumulative Methods from William Ibbs, Long D. Nguyen and Seulkee Lee, "Quantified Impacts of Project Change," *Journal of Professional Issues*

It is clear that the choice of method depends on the amount of project documentation available. The more documentation there is, the less uncertainty there will be in your estimate of the productivity loss. Additionally, with high project documentation, there is less effort associated with preparing the loss of productivity estimate. While it may seem that keeping large amounts of documentation is beneficial (and in many ways it is), it is not always possible or practical to keep the amounts of records that are required for some of these methods.

Realize that the uncertainty and effort are inversely proportional, and without experience and expertise, some of these methods can generate unreliable estimates. To double-check your calculations, it is prudent to use two or more of these methods.

Cumulative Method: Wrapping Up

The methods described in this chapter allow for estimating the total amount of productivity loss that is associated with multiple different changes, or a change that has different affecting factors. These are overviews of each of the methods, many of which have modified forms that allow for more precise measurements.

The methods for measuring the cumulative impacts from multiple different factors are either more qualitative, or based on the actual measured values. It is harder to estimate the impacts compared to the discrete methods that are described in previous chapters, but are useful if a job goes to claim or to quantify a series or accumulation of changes or conditions that apply to your job. Further there are many other statistical methods and models that quantify the cumulative effects of changes, but they are complex and require a more in-depth understanding of both the different variables and applications unique to each project. While it is important to understand the uses and applications of the cumulative methods, more in-depth research on the type of method you are using is recommended for successful application.

Part IV:

Wrapping Up

Changes on a construction site can be overwhelming. They can also have a significant impact on project success and profitability. By understanding the potential consequences of changes, you can not only alleviate some of the stress, but realize what actions to take and what costs to anticipate. This field guide aims to give you the tools necessary to anticipate some potential changes and their associated costs. You can mitigate some of the costs by anticipating the losses and taking corrective actions.

First, it is important to understand changes and their triggers. This will allow you to anticipate potential changes that could happen on your project, and stop them before they happen. While some changes can be predicted, others are unforeseeable. In both cases, it is important to take the correct actions to mitigate the costs.

After understanding what change is, the next step is to calculate the potential losses that are attributable to that change. The potential productivity losses will give a more realistic picture of the costs and time that are associated with the change.

With the information provided in this field manual, you can take an overwhelming situation and break it down to understand and deal with it in a productive way.

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William Ibbs is professor of Construction Management in the civil engineering department at the University of California at Berkeley. He teaches both undergraduate and graduate courses in construction management, including scheduling, labor productivity analysis, construction cost management and accounting, and project management. He is a leading thinker, researcher, and writer on construction management subjects.

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