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Evaluation of Risk in Change Orders Report for AKDOT Construction Staff

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Work changes are common in construction contracts, especially for large projects. When contract changes must be made, how the owner (the organization paying for the work) and the contractor (the firm performing the work) agree on a fair and reasonable cost can be as complex as a good poker game. It is usually in the owner's best interest to negotiate a lump sum price for changes before the new work starts (forward-pricing). Forward-pricing passes considerable risk (such as work delays, changing weather, getting new materials to remote sites, and re-scheduling other projects) to the contractor, who deserves some compensation for assuming it. The owner wants the best deal possible, and the contractor is the best judge of his (or her) own costs. The stakes can be higher in Alaska, where a short building season and remote locations can push a project into an additional year, with extra staging costs, staffing, and scheduling nightmares. This project, led by UAF engineering science management specialist Robert Perkins will produce a guide for AKDOT&PF managers and engineers that will better prepare them for judging project risk and estimating costs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Robert A. Perkins, Professor of Civil and Environmental Engineering, University of Alaska Fairbanks, was the principal investigator and responsible for all work on the project and for the content of this report.

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Report for AK DOT Construction Staff

Executive Summary and Guide

Changes are inevitable in construction contracts. The contract specifies the process for administering these changes. If the change involves alterations of the contract price or completion dates, a change order is issued by the Owner.

In most cases, the best method of dealing with change orders is for the Owner and the Contractor to agree to the price and schedule adjustment in advance of the changed work. This is referred to as "forward pricing" the change order. The Contractor will make a proposal based on an estimate of the gravity of the changed work and on the impact the changed work may have on the Contractor's original scope and completion schedule. Since the changed work will occur in the future, these estimates must have an allowance for the risks of future events. This risk allowance should be accounted for in the change order.

This monograph discusses how negotiators may arrive at a fair and reasonable price for the Contractor's assumption of change-order risks. The first four chapters present background information, and the fifth chapter summarizes the implementation.

First, the Owner must evaluate the contract in light of the situation and determine if the matter is a change at all. If it is a change, the Owner must consider the risks of not recognizing the change (ignoring it), issuing a time and material (T&M) change order, or proceeding to negotiations for a forward priced change. Chapter One discusses these alternatives, but this monograph assumes the Owner wants to use a negotiated forward priced change order.

Assuming that forward pricing of a change order is desirable for the Owner; the Contractor will be asked for a proposal with the estimated costs and schedule impacts of the change. The Contractor's estimate will have two main components, cost and "profit."

The term “profit,” is better termed “mark up,” and itself includes three components: home office overhead (HOOH), return on investment (which is closer to the accounting term of “profit”), and contingency. These three components of markup are often included into a percentage, which is applied to the cost. The markup components are discussed in Chapter Two. Chapter Three focuses on basics of contract law relating to changes and the theory of impacts and changes.

The Contractor’s estimate for the cost of changed work assigns firm prices to future events that are inherently uncertain. If the estimate is accepted by the Owner, the Contractor bears the risk of this uncertainty. While the entire future is uncertain, in risk management we divide that future into “risk,” for which we can state the probability and severity of the future event, even if only in general terms; and “uncertainty,” for which we do not know the probability or severity. We might term risk the “known unknowns” and uncertainty the “unknown unknowns.” This distinction is important, since we will incorporate the risk into the job cost estimate and the uncertainty into the contingency section of the markup. Uncertainty and risk are discussed in Chapter Four and tools are presented to allow conversion of future items into cost estimates.

In Chapter Five the background from the first four chapters is combined into a general procedure for evaluating risk in change orders. The procedures are not cookbooks, but rather information that should be considered in the negotiating process. Some numbers are presented, but these are suggestions rather than benchmarks.

When estimating the costs of a change order, there are three components. First is the cost of the changed work. Second are the known or foreseeable effects of the changed work on other work (These are referred to a “near impacts.”). And third is the unknown effect of the changed work on the project. The first two are included in the estimate of the costs of the change order. The third component is known as “indirect impacts” or “ripple effect,” and is not foreseeable and therefore can not be estimated. When Owners negotiate a change order, they want these indirect impacts included in the change and will draft contract language that includes these impacts in the change. Contactors want to use change order language that will allow them to be compensated for these indirect impacts, should they occur.

A fair change order price will have the costs of the changed work, including all near impacts, using estimate numbers that include an allowance for risk, such that the Contractor is “reasonably certain” the Contractor will accomplish the work for less than the estimated cost. In a detailed probabilistic estimate, “reasonably certain” would be the 90% confidence level. The markup allowed would have auditable percentages for profit and HOOH. In addition, if the Contractor agrees to change order language that requires the Contractor to assume the risk for indirect impacts, the contactor should have an allowance for contingency based on subjective factors; these are detailed in a Table of Adverse Cost Impacts in Chapter Five. An important point is that the contactor’s auditable profit percentage has risk built into it, but these derive from general business risks, not risks assignable to a particular change order.

Chapter One: Introducing Change Order Risk

A. Introduction to Report

Changes to construction contracts are inevitable. Contracts are written with the assumption that changes will become necessary. They provide authority for the owner to change the contract and a mechanism to equitably adjust other contract terms, such as the completion date and price. For significant or complicated changes, it is generally to the owner's advantage to negotiate all pricing and schedule adjustments before the changed work starts ("forward-price the change"). Similar to pricing in the original contract, forward-pricing transfers risks inherent in the additional work to the contractor, for which the contractor must be compensated. However, unlike the original contract, the compensation of the contractor for assuming these risks will be negotiated and not subject to the competitive forces that influenced the original contract bidding. This report discusses the evaluation and pricing of risks inherent in forward-pricing changes. It is the main deliverable of the Alaska University Transportation Center (AUTC) research contract #107059 between the AUTC and the Alaska Department of Transportation (AK DOT), entitled Guidelines for Risk Analysis.

The purpose of this report is to provide background for AK DOT construction managers in charge of pricing change orders. Included are references to relevant scientific, engineering, and managerial literature, standard nomenclature, and discussion of the issues that impact planning and estimating changes, common pricing problems, and likely claims. The author's intention is to expedite forward-pricing of changes and reduce claims by encouraging an equitable evaluation of risks. This project report will enable AK DOT managers and engineers to more accurately weigh risks during negotiations to forward-price a change order.

Chapter One reviews the overall issues. Chapter Two reviews estimating and scheduling basics with respect to risk and changes. Chapter Three reviews some basics about claims and changes. Chapter Four discusses the science of uncertainty and risk, and offers some practical analysis tools. Chapter Five combines the information from the first four chapters into some notes that AK DOT managers might use when preparing for change negotiations or when analyzing contractor claims. Chapter Five refers to earlier chapters and appendices for detailed explanations. Appendix A presents a glossary and acronyms. Appendix B consists of a list of references cited and a bibliography of further reading about the issues of risk in construction. Appendix C presents examples of risk analysis and pricing risks, and Appendix D contains information about recommended software.

B. Introducing Claims and Changes

Changes are common in construction contracts. It is usually in the owner's best interest to forward-price the change, that is, to negotiate a lump-sum price for the changed work before the changed work starts. These negotiations are fundamentally asymmetric, since the costs being negotiated are those of the contractor—the expert on contractor costs. The actual costs will accrue to the contractor. Although the goal of both parties is a fair and reasonable price and the owner's engineers are familiar with basic costs and estimating procedures, the owner also realizes that there are uncertainties that must be accounted for in the price. Since a firm lump-sum price will pass all the reasonably foreseeable risks of the changed work to the contractor, the contractor must be compensated for assuming these risks. Risks include delays to the work and impacts related to the effect of the change on the contractor's planned operations. In addition, Alaska's extreme seasonality and, often, the remote location of the project increase the risks of extending projects into the following year. A time extension can have severe direct-cost consequences because of a second mobilization. Additionally, an extension can have indirect consequences for the contractor's staffing and bonding capacity for other projects in the following year.

A contract begins by describing the general duties of both parties and defining the work to be performed by the contractor. Because changes to the work are almost inevitable, the contract permits the owner to change the definition (scope) of work to be performed and requires that, in the case of change, either an equitable adjustment to the contract price is made, or agreement is reached between parties that no change in price is warranted.

A new event or situation may arise that becomes the driver for change. Examples include differing site conditions (**DSC**) or user-required modifications.

Is the change within or outside the Contract Scope? The contract had a definite scope of work. Is a change within that scope? As a guideline, a change order that does not alter the nature of the thing to be constructed and which is an integral part of the project's objective is within the project scope. The AK DOT standard specifications require a "supplemental agreement" if the work is outside the scope but "in conjunction with" (Here and following, the square brackets indicate references in Appendix B.)[19, sections 1.01-1.03] the original contract [19, sections 1.04-102.2]. Such a change is essentially a new procurement; however, most of the following description will apply.

Is the event/situation recognized by the AK DOT as a change? If the AK DOT recognizes that the event/situation requires a change, the next step will be a negotiation and/or a Request for Proposal (RFP). However if the AK DOT does not recognize the necessity for a change, the contractor will be required to handle the event/situation as within the scope of the existing contract. If the contractor believes that a change should have been recognized, the contractor will treat the matter as a **constructive change** to the contract. For example, the AK DOT was a week late approving a contractor's asphalt mix design; the contractor, therefore, asked for a one-week extension to the contract finish date. Because the asphalt work was not scheduled to start for several months, the AK DOT did not believe the extension was warranted and refused. From the AK DOT's point of view, if the contractor has to accelerate the work process or use a different asphalt source, any additional expense is the contractor's liability, since the delay in approving the asphalt was not a change to the contract. Eventually such a matter may become a claim. There was no risk to the contractor from the new situation if it was not a change; the work would have to be done anyway. If it is judged a change by the contract review process or judicial proceeding, the contractor will be compensated under the contract via a claim process. However, there is risk to the AK DOT if the matter is likely to be deemed a change during the claims process because, in that case, the AK DOT would not be able to transfer the risks for the work (see below) to the contractor. Additionally, if the contractor is confident it will be awarded the change via a claims process, the contractor has no incentive to be efficient in the prosecution of the changed work. In the event of impacts to other aspects of the work or other changes, the AK DOT is in a weak position to affect the course of events and minimize its costs. (See Chapter Three for more on constructive changes.)

Some changes are recognized by the AK DOT. The AK DOT will ask the contractor for a proposal for the change to the original contract amount. (Other terms of the contract, such as completion date, might be included in the RFP.) For minor items, the RFP might be quite informal, perhaps just a confirmation by the contractor that there is no price change for some minor engineering change. In this case, there is risk to the AK DOT if proper records of the matter are not kept. For significant changes, the AK DOT will issue a formal RFP and request a written response. It is important to recognize that many such events/situations arise, requiring work in progress to be altered; the RFP, negotiations, and proposal may be concurrent with the contractor's changed work.

The standard AK DOT contract has several methods by which a change may occur:

1. If the contract change is minor with no expected change in schedule, the change can be accounted for by the contract's unit prices—more or fewer units at the contract unit price. The contract has a method for changing the prices of units, if the number of units is outside an envelope, 25% more or less and the item is a "major item," one that has a total value of 5% or more of the contract award amount [19, 109-1.04]. A change that forces the quantities outside the 25% envelope is a change to the contract, and the stipulations described in the next section will apply.

2. The AK DOT and the contractor agree to a firm contract adjustment—typically to price and sometimes to schedule [19, section 104-1.02.b]—referred to as forward-pricing the change. The contract terms described in *AK DOT Standard Specifications for Highway Construction, 2004* allow the AK DOT to direct the construction contractor to change the work and provide for equitable pricing adjustments. The preferred method of pricing is to negotiate the price before the changed work begins. This provides AK DOT with a firm price for budgetary and project management purposes and allows for

adjustment to the contract completion date, if needed. Such forward pricing transfers the risks from uncertainties associated with the change to the contractor. The negotiated price must then include some **contingency** for the unanticipated or unknown costs that the contractor may incur. While this is an issue in contract changes nationwide, it is an acute problem in Alaska, where the extreme seasonality and remote venues may increase risks. For example, a delay may force a project into a second season and thus require a second mobilization.

The goal of the negotiation is to achieve a fair and reasonable price, with an equitable distribution of risks and rewards. Standard contracts usually accomplish this goal; for example, risks of acts of God or differing or unknown site conditions are borne by the owner, while risks of labor inefficiency or mechanical breakdowns are borne by the contractor — the **party** best able to control each risk. Other risks are harder to allocate fairly; for example, an early freeze-up is not controllable by the contractor, but expediting the work to complete the job well before anticipated freeze-up is controlled by the contractor. Unseasonable rains may cause a work slowdown, but the amount of slowdown may depend on how skillfully the contractor varies techniques to deal with the weather.

In competitively bid work, it is assumed that the contractor's bid has accounted for foreseeable risks efficiently. If a contractor includes contingencies for all possible adverse happenings, that contractor will not be the low bidder. However, in negotiated work, such as change orders, the contractor has little incentive to under-price risks.

A second advantage to forward-pricing change orders is that the change automatically takes into account foreseeable impacts to the rest of the contractor's operations and altered completion dates. If the work is not forward priced and a time and material (T&M)-type change is utilized, the allocation of cost between the change and original contract, as well as schedules and impacts, may not be clear, and disputes may arise.

3. The AK DOT and the contractor may agree to T&M pricing for the change [19, section 109-1.05]. Standard specifications include T&M pricing formulae.

4. The contractor may believe a situation is not included in the original scope of the work, and the AK DOT may believe it is included. The contractor would be obliged to perform the work as interpreted by the AK DOT, then file a claim under Section 105-1.17 of the AK DOT's *Standard Specifications for Construction Contracting* [19]. Sometimes there are items that the AK DOT does not believe are changes mixed with items that are accepted as changes. If the AK DOT and the contractor are not able to agree, the AK DOT may unilaterally assign a price to the work for progress-payment purposes and to reduce the magnitude any later disputes. If the disputed work affects the schedule, the contractor would be obliged to complete according to the existing schedule, unless the AK DOT unilaterally extends the completion date. Without the unilateral extension, the required construction acceleration is similar to that which would occur if the AK DOT did not recognize the change at all.

C. Introducing Risks

1. Overview of DOT's risks

Each method of administering a change has risks. Not recognizing the change bears the risk that the work may not be prosecuted efficiently and the claims process may award the contractor its costs and profits. The claims process may impute bad faith or unfairness to the AK DOT. The risk to the AK DOT from forward pricing is likely to be small, and includes the risk that the contractor is able to negotiate a windfall, if it can get the work done for much less than the negotiated price. There is some risk to both the contractor and the AK DOT if there are unforeseen impacts to other work. We will discuss risks for the contractor in the next section.

For T&M, the AK DOT runs the risk that the contractor may not perform the work efficiently, since incentive to do so is lacking. The issue of completion schedule may be important; if the change does not address this, that is, if the completion date is not specified, the work may drag on. If the completion date is specified, the contractor may exert more effort than otherwise to keep to the schedule.

The AK DOT bears the risks of a unilateral construction change order. The risks are slightly greater, since the AK DOT has admitted the fact of the change to start with. This may be ameliorated slightly by a contractual requirement that the contractor keeps records of the changed work [19, 109-1.05.6].

2. Overview of contractor's risks

The contractor's risk in a constructive change is that the claims process may deny an award for the cost of the change or refuse some of the costs. At the beginning of the constructive-change process, there is little the contractor can do to minimize risks. The incentive to be efficient in the prosecution of the changes is proportional to the contractor's confidence that the claims process will award the change.

There are general risks to the contractor of forward pricing. Except for minor changes that can be accounted for by changed unit prices, a forward-priced change is preferred by the AK DOT, since it transfers risks of work-process inefficiencies to the contractor, the party best able to control these risks. (See below regarding impacts of differing site conditions.) Of course, the contractor wants to be compensated for bearing these risks. If the contractor is able to persuade the AK DOT that the risks are large, when they are not, the contractor may receive a windfall. If the contractor underestimates the risks, the AK DOT has some risk that the contractor may have financial difficulties that result in further claims or bonding issues. If the changed work encounters a DSC, the relevant clause in the general conditions of the contract becomes operative and essentially permits a change to the change to account for the DSC. However, if the AK DOT recognizes the possibility of a DSC claim, that possibility can be included in the change language, thus transferring that risk to the contractor. Impacts will be discussed in more detail below, but they include increases to the cost or complexity of the original scope of work due to work on recognized or constructive changes. If these impacts are foreseeable, they can likewise be transferred to the contractor via the change process, but again, the contractor will want to be compensated.

There are many uncertainties in construction and, generally, the occurrence of these uncertain events will increase costs. Contractors assume the risk of increased costs as part of the original contract; however, in forward-pricing changes, risk issues often arise. Who bears the risk of unseasonable weather? With Alaska's short construction season, delays into the colder months are risky for the contractor. Further delays may result in loss of an entire season. Risk can be clearly allocated in the language of the contract change, but since the contractor assumes the risks, a fair price for this assumption of risk must be determined. Although the contractor supervises construction operations, the success of those operations relies on many factors that are not under the control of the contractor, such as weather. Many other factors are influenced (but not controlled) by the contractor; for example labor productivity, equipment breakdowns, and some subcontractor and vendor pricing. While assigning these risks to the contractor encourages the most efficient operation, the contractor must be compensated for bearing these risks.

3. Details of contractor's risks

The contractor's risk may be categorized as direct and indirect. The direct risks are the obvious ones, such as increased costs. Delays in schedule completion, which affect costs via liquidated damages, extra costs due to overtime pay and inefficiencies, extra camp costs, and extra supervision, are also considered direct risks.

Direct risk may be divided further. Efficiency risks exist, both in conducting the changed work and in carrying out the original work. Time/schedule risks include loss of schedule float time, which leads to loss of flexibility and risks of impacts to other tasks in the original work. In Alaska, the risks of a seasonal shutdown weigh heavily on contractors faced with delay. Projects that require barge delivery of equipment or materials may miss critical shipping dates. All these risks will be further discussed in later chapters.

Examples of indirect risks include loss of bonding capacity if the job is not completed, dilution of the attention and supervision of upper managers, shortage of working capital, lack of capacity to estimate and bid new work, and so on.

Chapter Two: Estimating and Scheduling Basics Pertaining to Change Order Risk

A. Background
B. Cost components
C. Schedule
D. HOOH
E. Profit

In this chapter, we review some basics of estimating and scheduling that pertain to the forward pricing of change orders and the inherent risks. We emphasize concepts that may surface in negotiations.

A. Background

Every contractor's organization has a structure of responsibility and authority. The final bid-price decision authority is usually vested with the branch manager or owner of the firm. Often the corporate charter will specify the position with the authority to sign contracts for the corporation. Usually the **direct job costs** are estimated by an "estimator" who may or may not have a technical education. The estimator will be responsible for "taking off" the quantities, organizing crew size, identifying needed equipment, and "costing out" the project. Often a project manager (PM) is assigned to the project being bid or to several projects, which may lie within the PM's specialty area. The PM will often negotiate with suppliers and subcontractors and make decisions about likely subcontracts, camp arrangements, and supervisory personnel. Of course, in a small company the estimator and the PM may be the same person. Both the estimator and the PM may be bound by company policy. For example, the company may have a guide for internal equipment costs, or markups on third-party rentals. Often if the company must make a decision about whether to subcontract a service or provide it in-house, company policy might dictate which markups, or set markups, that will be used in the determination. Eventually the estimator and PM will determine a cost estimate for the extra costs to the company for performing the project. The company manager will then consider the costs to the company not directly due to the project—often known as home office overhead (**HOOH**). We will describe HOOH in more detail below, but first it must be recognized that HOOH is a valid cost. However, how the HOOH is allocated to any one project is completely arbitrary and is often only a paper exercise for estimate purposes. When the contractor calculates the company's profit or loss for the year, HOOH will not be allocated to particular projects; however to determine whether a particular project made or lost money, some allocation of HOOH must be made. In addition, at the estimating stage of the project, there is really no difference between HOOH and the next item: profit.

At this point, we will discuss the concept of a **neat estimate**. A neat estimate is the estimator's best estimate of what a particular item or items will actually cost. In contrast, a **fat estimate** includes embedded contingency; a "lean estimate" is so-called because the estimator is not confident the work can actually be accomplished for the price.

Although the estimator delivers a neat estimate for each item, it is understood that variability is inherent and the final costs of that item may differ. Usually this variability can be categorized by type of cost. For example, labor cost is typically highly variable, while the cost of subcontracted services or installed equipment is only slightly variable.

In accounting terms, "profit" is the difference between the company's costs and the revenue. However, in this context, we refer to profit as the "markup" that the contractor adds to the costs to determine the bid price. (Let's ignore HOOH for a moment.) In a competitive bid situation, the correct markup for a contractor is "all the market will bear," that is, the highest markup the contractor can add and still get the job. Contrast that with a negotiated price, where the ethical goal is a "fair and reasonable price." The two concepts may not be too far apart in a competitive bid with an adequate number of bidders, since each bidder has similar costs and needs a similar "return on investment" (discussed more below) in order to stay in business. Thus, in a "normal market" the lowest competitive bid will approximate a fair price. Note that this is not the situation when the market is not normal; for example, if all the contractors are very busy, a "seller's market" may exist, or the opposite may be true when there is little work and a "buyers market" exists. Of course, a change order is negotiated and is an extreme example of a seller's market. The owner can delete the changed work from the contract and hire another contractor to perform it, though this is usually impractical. Nonetheless, the hypothetical price to hire another contractor is the outside limit on the negotiated price.

To stay in business a contractor needs an adequate "return on investment." A contractor, at the start of business, may invest one million dollars in the company; the contractor had the option of investing this money in something else (the stock market, gold, etc.). Later, at any point in the business trajectory, the owners of the business have the option of divesting themselves of their interest in the business and turning their investment back into cash. One method of divesting, for example, would be to hold a "garage sale" of the parts and pieces. The price of all the parts and pieces of the business at the sale would be an estimate of the value of the business. By not selling the business, the owners are foregoing the profit they could make in an alternative investment, such as bonds or gold. By comparing the current profits of the business and the profits that they might make on bonds or gold, the owners can determine whether to sell the business and invest in something else. The price the business could be sold for is the amount of money the contractor foregoes by not selling, and is the basis used for calculating the rate of return.

Of course, even a qualitative evaluation of this is complicated by two concepts: goodwill and risk. **Goodwill** refers to the difference between what all those parts and pieces are worth at a garage sale and what an investor would actually pay for the business. Up and running businesses are worth more than their component parts because of the reputation of the business, skills of the business's employees, and value of current and likely future contracts. This goodwill is not on the contractor's balance sheet, but would be accounted for in the sale price of the business.

An evaluation of a return on investment must allow for the risks involved in the investment. Safe investments have the lowest rate of return, while "risky" investments demand a higher rate of return.

Below we discuss typical profit markups for construction contractors. Note that the markup or profit on the direct job costs will include HOOH and return on investment.

B. Cost Components

Here are some basic estimating concepts that may help in change order negotiation:

Direct costs include labor charges such as salary, employer-paid benefits, insurance, and taxes. The non-salary direct costs are sometimes called **burden**. The actual burden varies with employee type and union affiliation. In Alaska, the minimum salary and employer-paid benefits for workers on state contracts are established by Title 36.

Workers' Compensation and other insurance payments sometimes change during the course of a contract. Some insurance and tax payments may vary; for example, there is a maximum salary basis for FICA and other payments, so the actual amount paid would vary throughout the year. Two approaches to accounting for these costs are to account for each worker, or to use an average. However, variability in labor burden is generally small and the construction industry is generally knowledgeable about trends in these costs. The risk from labor is the amount of hours required for the work, not the cost per hour. This is generally true for all construction work, but may not apply in remote or difficult work, where workers are promised a certain minimum number of hours per week. If conditions are temporarily unfavorable, contractors may continue to work in order to keep their commitment regarding minimum hours. Also, if the labor market is tight, employers may balk at temporarily demobilizing crews for fear that they may not be able to rehire skilled workers.

The word *equipment* has two different meanings. "Installed equipment" refers to machinery or equipment that is incorporated into the finished job. Streetlights are an example. "Operating equipment" refers to the equipment used on the job, such as bulldozers. The risks of these two types of equipment are quite different. Installed equipment is generally not considered a variable with risk. Shipments are generally insured through installation, in case of damage or pilferage in storage. A contractor does have a cost risk with special-order installed equipment. If a shipment is delayed, the contractor generally cannot recover more than the shipping cost, while the damage to project operations may be a much larger amount. On the other hand, owner-supplied equipment is considered risky for the owner, since delays in procurement or transport may delay the contractor. Most public owners include the purchase of installed equipment in the bid to distribute those risks to the contractor.

Operating equipment is considered slightly variable in vertical (building and most industrial) construction; however, it is more variable in horizontal (heavy) construction. The costs of equipment operation may be divided into three parts: ownership costs, operating costs (non-labor), and operating labor. Most heavy construction operating equipment is charged by the operating hour. However, some of the ownership costs are incurred even if the equipment is not working, so most contractors have a cost for “standby.” The operating hours may vary from the estimate, of course, and these are variable. In addition, the operating costs (non-labor) may vary depending on the conditions encountered; for example, if the soil is more competent than planned, the equipment may wear more quickly and need repairs more often.

The State of Alaska uses the **Blue Book** [25] for pricing T&M change orders and often as a guide in negotiated work. The Blue Book sets rates for each type of equipment. There are rates for equipment ownership and operating costs. Operating labor is not included. The Blue Book rates include the labor of the mechanics doing equipment repairs and maintenance in the operating costs. Since there are regional adjustment factors, these presumably adjust for the higher costs of labor in Alaska. In many remote jobs, however, the contractor will have a mechanics’ shop with labor. If a T&M change order were used, the mechanics’ labor generally would be part of the Blue Book operating costs, not job labor costs. However, in a negotiated change order, the costs of these mechanics need to be considered. The Blue Book has adjustment factors that need to be considered as well.

Small tools and consumables present additional costs. Most contractors allow a percentage of labor for small tools (generally less than $500; for example, shovels) and consumable supplies (for example, safety glasses and earplugs). Some items may be estimated or lumped into small tools. It is generally impractical to account for these. This percentage should be no different on changed work then on the original contract. However, some items might be treated differently, depending on the situation. For example, survey hubs might be estimated for a job requiring substantial initial survey work, but might be considered a consumable for a job that requires only a little surveying. If a large amount of consumables is likely, it is important to establish where those costs are located in the proposal. Also, most contractors handle this by starting a job with a trailer or warehouse filled with consumables from the last job, topped off with any special supplies that will be needed for the current job. As items are used up, the current job orders replacements, which are charged to the job. Thus, while invoices are available for the consumables charged to the job, it would be necessary to inventory all the consumables at the start and end of the job in order to have an exact accounting. This is seldom worth the trouble.

Housing costs are generally fixed per worker-day, so any delays to the project will proportionally increase the housing cost. In addition, delays to special crews may require that the crew stay longer in the camp, even though the overall job is not delayed. An additional issue is total camp capacity. If the camp is full, additional crews or shifts cannot be added.

Transportation costs are important in remote work, where the contractor frequently has to pay for transporting workers to the jobsite.

There are two **bonding** issues relevant to change orders. First, there may be a direct charge to the job if the change order is large, since the bonding company is now insuring a larger project. Second, if the scope/size of the job or the job duration increases, the contractor's bonding company may not permit them to bid new work. This is not a cost as such in HOOH, but does adversely impact the contractor's business.

The job overhead costs, including jobsite supervision, engineering, administration, the supporting physical plant, and equipment, are considered slightly variable. They are typically costed in the original bid based on known costs, and then these costs are spread over the estimated duration of the job. (Sometimes the mechanic's shop and catering and remote services are also considered in this category, but here we will assume not.) So, regarding changes that delay the job, these costs are generally assumed to increase linearly with the duration of the job. If the job takes 10% longer than estimated, these costs are assumed to increase 10%. Thus, an owner-initiated change, for example a delay in access, only affects the completion date; the change in job overhead is straightforward. Contractor costs may vary, however, because of differences in job overhead due to the change order, not directly due to changes in duration; for example, the addition of a second shift will require more supervision and administration. The issue of dilution of supervision due to changes is an important impact discussed below.

Most DOT contracts are let by unit prices with estimated (or "plan") quantities. On the job, if quantities vary somewhat, the overall price adjustment is straightforward. The standard contract requires use of the bid unit prices when the actual quantities vary less than 25% from the plan quantities and the nature of the change does not "materially differ in character or unit cost from specified contract work." The bid unit prices might not be used if the nature of the changed work differs materially from the original work or the amount of the change is more than 25% from the plan quantities.

Some caution is needed when using bid unit prices for changes. Bid unit prices are composite prices of the neat labor, equipment, etc., in the unit, an allocation of jobsite overhead, and an allocation of profit (contingency, HOOH, and return on investment). There is no rule that these allocations must follow a particular format, and the contractor is generally free to allocate more to units that occur early in the job or (more rarely) units for which the contractor believes the actual will be more than the plan quantities. As long as the allocation is reasonable, there is no basic legal (or in the author's opinion) ethical problem with so allocating. However if the bid is "unbalanced" the contractor accepts some risk; for example, if a bid item must be rescheduled to later in the job, or some early job items under-run their quantities and some late job items overrun. The foregoing is presented here to illustrate how bid unit prices can be used to estimate change orders. Clearly, for minor changes that just increase or decrease quantities, the bid unit prices must be used. However, for changes that are not minor, the use of bid prices may not be fair to one party or the other.

Another item in unit prices is the notion of fixed versus variable costs and learning curve. Aside from the fixed (generally) costs of job overhead, HOOH, and job mobilization and demobilization, it is common for activities to carry their own fixed costs; typically, each activity has a "ramping up" phase, and many have a mobilization phase and often a "learning curve." The effect of these "fixed" costs for each activity will tend to reduce the unit cost when quantity overruns occur, and increase cost in under-runs. While this is logical and well known, it may become problematical if, for example, a change order disrupts an activity. Will these fixed costs for the activity need to be repeated when the activity resumes?

Terms from the industrial process that may be useful are **marginal** and **average costs**. The marginal cost is the cost to produce one more unit. If the variable costs are linear, then the marginal cost is the same as the variable cost. If the cost of vendor-supplied parts is $5/each, then (with respect to the component of cost due to that part) the marginal cost and variable cost are the same.

Sometimes the variable costs are not linear. For example, the cost of the part might be “$5/each up to 100 parts, $4/each for between 100 and 500 parts, and $3.50/each for over 500 parts.” In this case, the marginal cost, that is, the cost of the next unit, will be different if we are inquiring about the marginal cost of the 99th item versus the marginal cost of the 101st item. The **average cost** usually means the total cost of the production divided by the number of units produced. If **fixed costs** are indeed fixed and the variable costs are linear, the average cost will decrease with increases in production volume. This leads to the concept of **economy of scale**.

C. Schedule

In later chapters, we discuss scheduling in some detail. Here we note that scheduling the work is a part of the estimating process. The estimator must allow enough time for preliminary crews to complete their work for the follow-on crews. Thus, there will be an initial schedule of the crews and completions of various phases as well as for the overall project. These estimating schedules, in turn, will be used to estimate the direct overhead costs of the job. The effect of the schedule on the HOOH may be direct or indirect. The most common indirect effect is on bonding and financing. Bonding companies generally limit the total value of projects that they will insure. If a contractor is nearing the limit for bonding capacity, one job must be finished before another is started. While the costs of a bond for a particular project are a direct cost to that project, the loss of bonding capacity is a HOOH matter. In addition, many projects (although not State of Alaska projects) have a “retainage” until job completion. The contractor must complete the project in order to be paid the retainage. Even in Alaska, where state agencies do not hold retainage, there is a time lag in the billing and payment cycle such that the contractor will not receive payment for four to eight weeks after expenses are incurred. Most accounting schemes, as well as standard governmental auditing procedures, do not allow interest charges on working capital as a charge to a particular project; thus, any extra interest costs due to schedule delays will be charged to HOOH. This can be especially difficult for contractors, since interest charges are not usually allowable costs for governmental audits.

It is important to consider "Critical Path." We might consider scheduling two different types of work: discrete and continuous. Most of the literature and standard programs handle discrete work. For example, for a short bridge, the pile driving at each end of the bridge and the forming and pouring of the pile caps are examples of discrete tasks. They are sequential on each side of the river, since the caps cannot be formed until the piles are driven. Also, if there is only one pile-driving crew, the piles on one side must be driven before the second side is started. For highway construction, there is a sequence of tasks, including subbase and base installation and paving, but they are continuous. For discrete construction, a **CPM (critical path schedule)** is usually the best choice of scheduling method. For construction of continuous work, a **linear scheduling method (LSM)** is often best [26]. The following applies directly to discrete CPM scheduling, but the concepts can be extended to continuous LSM scheduling.

Often in construction there are many activities occurring concurrently. Some of these activities have **slack** (AKA **float**); that is, the activity can be delayed without delaying the next activity or the entire job. Other activities cannot be delayed without delaying the next activity or the entire job. Activities that cannot be delayed without delaying the entire job are referred to as "critical." These activities will have zero slack. The sequence of activities that are critical is called the critical path of the job. There can be more than one critical path. When an activity with slack is delayed sufficiently, the slack is consumed, and the activity becomes critical. At first consideration, therefore, a change that delays an activity but does not consume all the activity's slack will not increase the overall job duration. Changes that consume all the slack will increase the job duration.

Faced with a delay on the critical path, the owner or contractor can either speed up the delayed activity or speed up subsequent activities that are also on the critical path, or accept a delay in project completion. The process of speeding up an activity is sometimes called **crashing** the activity. The implication is that there is a tradeoff between the costs of crashing and the costs of the delayed project. The significance of this tradeoff for change order risk is that, if the changed work delays work on the critical path, the owner can acknowledge this and pay for the crashing of the required activities or accept the delay of the project. The risk to the contractor from accepting a change is that it will affect items on the critical path and thus require paying for the crashing or paying for the delay in the project.

Bar chart schedules have the advantage of simplicity—they do not take any special education to make them or understand them. While a bar chart shows the anticipated start and finish of activities, it does not show the dependence of one activity upon another. It is generally impossible to prove or disprove a claim for extra time with use of bar charts.

The following are some general comments regarding schedule and change orders:

1. The standard DOT contract [19] calls for the contractor to submit "a progress schedule, in a format acceptable to the Engineer, showing the order in which the Contractor proposes to carry out the work and the contemplated dates on which the Contractor and the subcontractors will start and finish each of the salient features of the work, including any scheduled periods of shutdown." The standard contract also presents the idea of a critical item (called a "controlling item"), but defines that as being determined by the owner's engineer and not tied to the contractor's submitted schedule. Hence, there is no requirement for a critical path schedule.
2. There is no requirement [19] for the contractor to update the schedule regularly as the job progresses, unless there is a substantial change or the engineer requires it.
3. When evaluating the contractor's submitted schedule, it is important to remember that no benefit is drawn from showing project activities with slack. If all activities were critical, any owner-caused delay to any activity would delay the job and be an excusable delay.
4. Most basic CPM schedules do not show the resources (special personnel or equipment) that each activity requires; thus, a special schedule with resources is also required. When organizing a project, the main crew and equipment (resources) are scheduled on a first pass, and then the activities are adjusted in order to "level" the resources. However, owner changes that change activities may cause a gap or overlap in the resources that are shared between activities. The point is that activities may be linked by their operations; that is, the base for Mile 8 must be compacted before the asphalt for Mile 8 is laid. However, they

may be linked by resources; the roller for the base may also be used for the Mile 10 subbase. A last-minute grade change in Mile 10 may delay the roller and thus delay the work on Mile 8, even though, based on operations, the activities are not related.

5. Proper schedules show each activity with its slack; for example, a 5-day activity must occur within a 15-day time slot, and thus there is 10 days of slack. This implies that the owner can delay that activity 10 days without delaying the job. While that may be true, it may not be true that the owner can delay that activity 10 days without costing the contractor money. Presumably, the contractor's superintendent has planned each major piece of equipment and crew for each day. Any disruption to the schedule can cost money through disruption or, via resources issues, to other activities [12].
6. As slack is consumed, other critical paths emerge; more critical paths mean a greater chance that the contractor will be late. Most likely, estimators would estimate higher if there were no slack. One author approached the value of slack by taking the difference between the estimate with all the slack available and subtracting it from the estimate with no slack. That difference, divided by the days of float in the first estimate, yields the cost per day of float [13]. While I would not present such an analysis as a quantitative estimate, this approach makes it clear that float does indeed have a value.
7. **Unit price** increases: The specifications [19] say, "Contractor shall take into consideration and make due allowances at the Contractor's expense for foreseeable delays and interruptions to the work such as unfavorable weather, frozen ground, equipment breakdowns, shipping delays, quantity overruns, utility work, permit restrictions, and other foreseeable delays and interruptions." Therefore, quantity overruns up to 25% on major items should be accommodated without delaying the project. However, the nature of the work that increased the quantities must be both foreseeable and not "materially different" than those provided for in the original contract.

D. HOOH

When evaluating HOOH, contractors generally have firm guidelines to indicate what is included in overhead and what is not. For example, while the company president and comptroller are always overhead, and project engineers and superintendents are always charged to a project, project managers may be charged to a project, charged to overhead, or allocated between several projects. The key in evaluation is to determine the contractor's policy and make sure it is consistent. This avoids being double-charged: once as a direct expense and again as part of overhead expense. Some contractors have a "shop" or warehouse that is staffed by (union) trade labor or salaried (non-union) staff. Whether the costs are charged to overhead or charged to projects via a "work order system" also varies between contractors. Note that for the contractor's internal record keeping, it does not matter how these are charged, as long as the method is consistent. For evaluating change orders, it may matter. If the charges are overhead, they are included in the contract or regulations' fixed-overhead rate, if such a rate exists, and it often does. Therefore, it would be to the contractor's advantage to charge these expenses to a job also.

One approach to assigning HOOH to projects is the **Eichlay formula**. Eichlay was the name of a contractor who was delayed on a federal project. The federal claims board used a formula to compute compensation for HOOH [20]. While the name Eichlay is often used, it is important to keep in mind that Eichlay was a very special case in which the contractor was 100% stopped on the project due to the action of the owner (the government), but was not allowed to demobilize or start other projects because the owner did not know how long the delay would last. (The concept seldom applies directly to construction contracts.) The Eichlay formula is simply all the HOOH for the year, divided by the number of projects the contractor completed, divided by 365, and then multiplied by the number of days the contractor was shut down. If all projects were of approximately equal size, the formula would be quite logical. There are several modifications to the formula that are bandied about from time to time. The chief issue with Eichlay, however, is that this formula generally does not apply to construction delays; usually the contractor continues to work and will be compensated for the direct project costs of the delay.

Some expenses are non-allowable. Generally, interest charges are not part of HOOH because it is assumed that interest is part of the financing scheme of the company; thus, the company will be compensated via profit. This is generally logical. Other expenses, such as entertainment, are sometimes disallowed by governments as a matter of policy, although they logically belong in HOOH.

Bidding expense is a large component of HOOH for construction contractors. Special home office expenses for organizing and engineering a large, complex change order might be significant. These are often correctly charged to the change order, especially if the contractor must use outside consultants.

E. Profit

Unless "contingency" is a separate line item, it is included under profit. So, assuming the costs are accurately estimated and are a neat estimate, what is a reasonable allowance for profit and how much contingency should be included? We will separate risks that can be evaluated as part of the cost estimate from uncertainties that cannot be evaluated, and here assume it is these uncertainties that belong in contingency. Most contracts include HOOH in the profit line as well. We will start by examining standard profit, and try to determine the extra profit that is fair compensation for risk.

Within the contractor's estimate, we may divide the types of costs into categories, based on their risks.

A. Labor and "burden." Burden includes costs that are attached to salary, such as fringe benefits, taxes, and some insurance.
B. Equipment and purchased materials incorporated into the job
C. Operating equipment that consists of ownership costs and operating costs
D. Subcontractors
E. Expendable materials and small tools (typically less than $500 in purchase). This may be a percentage of Category A, labor.

Of these, labor is the most variable cost, followed by operating equipment. Purchased materials and subcontractors are usually not considered variables.

Sarvi [4] interviewed eight San Francisco Bay Area water and sewer and transportation contractors regarding how they calculated profit in their bidding practices.

Four contractors used 8% to 15% of A + B + C +D—roughly the total cost. Several others used a percentage of that sum, or 10% of A, 35–40% of A+C, or 40–100% of A, whichever is greater. For example, one used 15% of the total costs (A+B+C+D) or 100% of A, whichever was greater. One used 50% of A. This is not much different from the percentage that the author's employer used in that area in the 1970s: 10% of total, 30% of A+C, or 50% of A, whichever was greater.

From these examples, we may take 10 to 12% of total estimated cost to be an average. However, this percentage would be for a competitive bid, not a change order, where the work is negotiated non-competitively. Sarvi's figures do not account for risk. That is, the interviewed contractors apparently did not receive a higher percentage for risky work. They may have received a higher percentage and not given the information to Sarvi, or they may have accounted for risk in their estimation of costs. In addition, those percentages assume HOOH is in the profit percentage.

One approach to risk and profit is used by the federal system. The DFARs (Defense Federal Acquisition Regulations), Section 215.404–4, presents the weighted guideline method for calculating profit, which breaks profit into factors and allows the government's negotiator to determine a negotiating position. Examining two versions, one for general purchases and the other from the Corps of Engineers, which relates to construction, we find that both relate allowable profit to job conditions, which implies some guidelines for profit and risk. The federal system has a price for HOOH, called **General and Administrative** (**G&A**), which is added to the job cost before the profit is calculated [22].

The standard guideline, which is not necessarily for construction, recognizes "contract type risk" and "performance risks," and divides performance risk into technical and management/cost control. For standard contracts, the "normal value" of contract type risk is 5%, with a "designated range" of 3% to 7%. The guideline includes a subjective list of risk factors, such as:

(i) The contracting officer may assign a higher than normal value in those cases where there is a substantial technical risk. Indicators are—for example- (C) The services and analytical efforts are extremely important to the Government and must be performed to exacting standards; [or] (ii) Extremely complex, vital efforts to overcome difficult technical obstacles that require personnel with exceptional abilities, experience, and professional credentials may justify a value significantly above normal.

For firm fixed-price contracts with no financing, the normal technical and management/cost control percentage is 5% with a range of 4% to 6%. The profit is the sum of the two, so the range is 7% to 13%, and one could infer that this difference, 6%, is due to risk.

Here is a similar algorithm from the Corps of Engineers, which pertains to construction directly:

	Low	**High**	**Rate**	**Low Value**	**High Value**	**Notes**
Degree of Risk	0.03	0.12	20%	0.4%	2.4%	Where the risk is very small, weighting should be 0.03.
Relative Difficulty	0.03	0.12	15%	0.4%	1.8%	If the work is most difficult and complex, the weighting should be .12.
Size of Job	0.03	0.12	15%	0.4%	1.8%	Work 100 thousand to 5 million, work less than 100 thousand weight at .12 5 million to 10 million at 0.04 Excess of 10 million at 0.03
Period of Performance	0.03	0.12	15%	0.4%	1.8%	Jobs in excess of 24 months are to be weighted at .12.
Contractor's Investment	0.03	0.12	5%	0.4%	0.6%	Rate at below average, average, above average
Assistance by Government	0.03	0.12	5%	0.4%	0.6%	Basis of average to above average
Sub-contracting	0.03	0.12	25%	0.4%	3.0%	80% or more, rate at 0.03
				3%	12%	[23, 24]

This chart would permit a markup for profit and risk of from 3% to 12%, indicating that up to 9% of the profit may be risk. For both these DFAR algorithms, about 10% overhead has been added to the cost prior to these risk/profit calculations. This would bring the total markup to from 13% to 22%.

Regarding markup for change orders, the table that follows is from Sarvi [4], published in 1992:

TABLE 2. ALLOWABLE CHANGE-ORDER MARKUPS											
Agency	Lump-Sum Percentage of			Force-Account Percentage of			Bond allowance	Allowable markup on subs	Labor surcharge	Markup includes field staff	Markup includes small tools and supplies
	Labor	Material	Equipment	Labor	Material	Equipment					
BART	20	15	15	20	15	15	1	15	—[a]	Yes	Yes, up to $200
Caltrans	33	15	15	33	15	15	0	5[b]	29[c]	Yes	Yes, up to $200
Central Contra Costa Sanitary District	—[d]	—[d]	—[d]	33	15	15	0	0	29[c]	Yes	Yes, up to $500
City of Concord	33	15	15	33	15	15	0	5[b]	29[c]	Yes	Yes, up to $200
City of Los Angeles	20	15	15	20	15	15	0	5	—[a]	Yes	Yes[e]
City of Pleasanton	33	15	15	33	15	15	0	5[b]	29[c]	Yes	Yes, up to $200
City/County of San Francisco	—[f]	—[f]	—[f]	24	15	15	0	0	29[c]	Yes	Yes, up to $100
City of San Luis Obispo	24	15	15	24	15	15	1.5	10	29[c]	Yes	Yes, up to $100
City of Santa Rosa	33	15	15	33	15	15	0	5[b]	29[c]	Yes	Yes, up to $200
City of Walnut Creek	33	15	15	33	15	15	0	5[b]	29[c]	Yes	Yes, up to $200
Contra Costa Water District	20	20	0	20	20	0	0	—[g]	—[a]	Yes	No
Corps of Engineers	—[h]	—[h]	—[h]	—[h]	—[h]	—[h]	—[f]	—[f]	—[a]	Yes	No
Delta Diablo Sanitation District	20	15	15	20	15	15	0	5	—[a]	Yes	Yes, up to $100
East Bay Municipal Utility District	20	20	20	20	15	15	1	10	27	Yes	Yes, up to $150
North Pleasanton Improvement District	33	15	15	33	15	15	0	5[b]	29[c]	Yes	Yes, up to $200
Union Sanitary District	20	15	15	20	15	15	0	5	—[a]	Yes	Yes, up to $100
Vallejo SFCD	15[i]	15	15	15[i]	15	15	0	0	—[a]	Yes	No

[a]ACTUAL COSTS OF TAXES AND INSURANCE ARE REIMBURSED.
[b]APPLIES TO FORCE-ACCOUNT WORK ONLY.
[c]THE AGENCY ALLOWS 30–39% FOR SPECIALIZED CRAFTS.
[d]ONE SET OF MARKUPS NEGOTIATED FOR ENTIRE PROJECT OR FOR EACH INDIVIDUAL CHANGE ORDER ON SOME PROJECTS.
[e]NOT SPECIFIED.
[f]NEGOTIATED AT THE START OF CONSTRUCTION.
[g]5% IF ONE SUBCONTRACTOR IS INVOLVED, 10% IF TWO OR MORE SUBCONTRACTORS ARE INVOLVED. DOES NOT APPLY TO EQUIPMENT COSTS.
[h]OVERHEAD IS NEGOTIATED. PROFIT OF 3–12% CALCULATED BASED ON WEIGHTED FACTORS FOR EACH CHANGE ORDER.
[i]APPLIED TO LABOR COSTS BEFORE LABOR SURCHARGE IS APPLIED.

It is remarkable that no one offered higher markups for negotiated work than T&M or “force account”; hence, there was no incentive to forward price.

Saunders [5] has allowable markups, published in 1996, from owners’ standard contracts, mostly DOT and transit authorities. He applied those markups to a typical mix of heavy construction costs and came up with a net markup range of 7% to 21%. When Saunders’ mix is applied to the typical markups in Sarvi’s table, the net markup is 11% to 18%. Both show a wide range.

The author has reviewed parameters of current state DOT T&M contracts, and they are included in the table below:

DOT Markups on Force Account (details omitted) 2007					
	Alaska	**Colorado**	**Florida**	**Indiana**	**Ohio**
Labor	35%	67%		20%	38%
Materials	15%	15%		12%	15%
Equipment*	BB	BB	BB	BB	BB
Rented	15%	15%			
Sub	5%	10% TO 3%	10% OR 5%	10% then 7%	5% limit of 10K
Expendables		10%			
HOOH				Allowed	
On Total Cost			17.5%		
Saunders' Costs**, $1550	$1922	$2192	$1821	$1794 +HOOH	$1948
				1871 at 5%	
Profit and HOOH	24%	41%	17.5%	20.7%	25.7%

*Blue Book [25]
**The cost mix Saunders used was $600 bare labor, $250 labor burden, taxes and insurance, $200 material, $400 owned equipment costs, $100 subcontracted for a total of $1550.

We note that profit, other than in Colorado, varies from 17.5% to 25.7%, which is a narrower range than Sarvi or Saunders found. This is force account work and does not carry risk. The current AK DOT specifications do not specify suggested markups for negotiated work. One would assume that the profit allowed would be higher for forward-priced work.

To summarize profit, we present percent markup ranges, which include profit, contingency, and HOOH. The first two categories have been analyzed to postulate a rate for risk, for negotiated changes, and for bids. The third category shows the range of allowed profit for T&M work, where there is presumably no risk, and thus this category only shows variability in owners' approaches.

Contract Type			
	Fixed Price, Bid, differences indicate range		
	Low	High	Range
SF Bay area, heavy construction	10%	12%	2%
	Fixed Price, Negotiated, difference indicates value of risk		
	Low	High	Risk
DFARs, general, plus 10% HOOH*	17%	23%	6%
DFARs, Corps, construction	13%	22%	9%
	T&M, difference indicates variability		
	Low	High	Average
SF Bay area, heavy construction	11%	18%	14.5%
Southeast US, heavy construction	7%	21%	14%
Typical DOTs	17.5%	25.7%	21.6%

*Home Office Overhead is audited for federal work. Here it is estimated at 10%.

Note that the low end of the markups with the lowest risk values are 17% and 13%; the average of T&M markups that do not include risk are 14%, 14.5%, and 21.6%. On the other hand, the markups for competitively bid work, which includes risk, fall between 10% and 12%. The profit percentage is about double in negotiated and T&M work, compared to bid work. Some caution is needed, since Sarvi's work was in the early 1990s and may represent a buyer's market.

Chapter Three: Claims and Changes Basics

A. Changes

1. Introduction

Under the basic common law of contracts, each party is obliged to perform their part of the contract exactly. If a party does not perform exactly, it is in breach of contract and liable for any damages that the non-breaching party or parties may incur because of the breach. The owner, having supplied the plans and specifications for the project, would be in breach of contract if the design were insufficient or flawed. Likewise, if the owner wanted to change part of the design, the contractor could refuse. If the owner withheld payment or otherwise tried to force the contractor to do the work differently than the contract described, the owner would be in breach of contract. Because all construction projects will have changes, all construction contracts have specific contract language that permits the owner to make changes to the project design or other contract features or terminate the contract altogether. In turn, the contract assures that the contractor will receive an equitable adjustment of the contract price for any changes made by the owner. Further, the contractor cannot refuse to make the changes requested by the owner, provided they are within the scope of the contract. Here we review some basic contract principles with respect to change order risks.

2. Unit price contracts

For our purposes, small changes in **estimated quantities** of **unit price contracts** are not a change in the contract, although they often change the final contract price. The amount of quantity change that would force a renegotiation of the unit prices is set out in the contract; changes in quantities beyond that amount would be a change to the contract.

3. Cardinal changes to contracts – different contracts

How much can an owner change a contract and still have the same contract? Generally, the change must be "within the scope" of the original contract and, further, what was contemplated by the parties. For example, if a contractor has been hired to resurface a runway at a remote airport, a change in asphalt mix or size of parking area certainly would be within the scope of the original contract. A reasonable contractor bidding the work would realize that the owner might change the specifications or change some dimensions. On the other hand, building a new hanger would not be within the scope. Thus, the resurfacing contractor could ignore a directive to build the hanger. As a practical matter, the parties could negotiate a change to the contract that expanded the scope in any direction, but making those out-of-scope changes would be optional for the contractor. Of course, public owners, who are bound by government procurement statutes and regulations, are often limited in how far they can stretch the scope of a project without running afoul of those laws. Such an occurrence generally would require a different procurement process when the new work is identified as a new project, beyond the scope of the original contract.

A different situation arises when the owner demands that the contractor perform extra or different work that is generally within the scope of the contract, but which, due to the volume of the changes or their nature, changes the work beyond what a reasonable contractor might have contemplated when bidding the work. For example, changing the main structure of a building from concrete to steel would be a cardinal change, even though the outward appearance of the building remains the same. It is also possible for the owner to make so many changes that the contractor cannot keep up with them and, at some point, insists that a **cardinal change** has occurred—that the owner has breached the contract, even though any one or several of the changes would have been within the scope.

4. Constructive changes

Sometimes an owner and a contractor disagree on whether a particular event constitutes a change in the work. Often these differences involve interpretation of the contract or specifications. The owner directs the contractor to proceed with the work as the owner interprets the contract and, thus, refuses to call the directives "changes" or to change the contract price. In contrast, the contractor believes that the directives constitute a change. In this case, the contractor is obligated to follow the owner's directives, but will insist that the matter is a change and (usually) ask for more money and/or a time extension. As a legal matter, if the owner orders a change, but does not follow up with the requisite change order paperwork, the contractor is confronted with a **constructive change** [28, p. 243] and must reschedule and reorganize his work to accommodate the change. Assuming that a court or claims board later determines that a change order should have been granted, the owner is in a poor position to contest any of the contractor's claims for damages. There is risk, therefore, in not granting a change order when the situation calls for it. Frequent causes of constructive changes are disagreement over the meaning of the contract (noted above), defective specifications that the contractor must fix, and constructive acceleration (see below) when an owner fails to acknowledge an excusable delay. Another cause of constructive changes is failure of the owner to cooperate, for example, if other contractors are not performing.

5. Pricing changes

Although the owner can force a contractor to change the work and the contract will include mechanisms for pricing the changes, it is to the owner's advantage to forward-price the change, that is, to negotiate changes in price (and perhaps completion dates). If changes are not pre-negotiated, the contractor has little incentive to do the work efficiently, to the detriment of the original contract work. An additional advantage to the owner for forward-pricing the change order is that, because the changed work is often intertwined with the original work, it is difficult to distinguish them for costing purposes. Finally, changed work will often interfere with original work, and changes tend to snowball or experience a **ripple effect**. A forward-price change, however, can take interferences into account. (Note that this can become quite convoluted as changes mount. Also, contractors are likely to withhold the right to make claims, see below.)

Table of AK DOT Standard Specification Clauses [19] Pertaining to Changes

Common Name	**Standard Spec**	**Description**
Owners right to change	104-1.02 1.	Within scope changes
Quantity changes within scope	104-1.02 1. a.	Contractor must perform at original unit prices
Outside of scope forward price	104-1.02 1. b (1)	Forward-price change by negotiation
Outside of scope T&M	104-1.02 1. b (2) and 109-1.05	First defines T&M, and second gives details of how it is priced out
Outside of scope	104-1.02 1. b (3)	Unilateral change based on engineer's estimate
Deletion	104-1.02 1. c	According to 109-1.09, no profit on minor deleted items. Negotiate major deleted items
Outside contract scope	104-1.02 2.	Need Supplemental Agreement
Differing site conditions	104-1.03	(standard)
Claims	105-1.17	Contractor shall make owner aware, etc., procedure
Progress	108-1.03 1.	Progress schedule required five days before prejob
Time extensions	108-1.06 3.	List of excusable delays
Suspension	108-1.06 4.	Compensable delay if Department does not fulfill a contract obligation

There are three basic methods of pricing the changed work: forward pricing by negotiation, T&M, and a unilateral change order. With a unilateral change order, there is no agreement about price or completion, but the contract is amended with a price and schedule adjustment based on the engineer's estimate, and the contractor keeps track of the extra work involved. With forward pricing, the contractor can add job overhead, HOOH, and profit to the price of the change order, as the negotiations allow. The T&M provisions of the specifications include a formula for calculating those items. For a unilateral change order, the contractor is likely to file a claim for any differences between his costs and the engineer's estimate. The owner may lose control of the cost and schedule of the work, since the contractor will interpret any directions as being new change orders. Job site overhead, HOOH, and profit are likely to be contentious items in the claim.

B. Delays

Construction contracts have completion dates, and the contractor is liable for the owner's damages if the contract is not completed by those dates. Because actual damages are often difficult to compute, most public construction contracts have a **liquidated damages** clause, whereby the parties agree to the amount of damages, usually stated in dollars per day. If an owner-ordered change will delay the contractor such that the contractor can no longer complete work by the specified date, the contractor will ask for an extension of the contract time. (He may also do this if the contractor planned to complete work early.) If the owner will not grant the extension, the contractor must accelerate his work to finish on the original schedule, thus increasing the price that the contractor requires for the change. There are two ways—not mutually exclusive—in which changes that affect the schedule can increase the price beyond the direct cost of the change. First, if the completion date is not extended or not extended sufficiently, the contractor will incur costs in order to accelerate finishing the work on time. Second, if the completion date is extended, the contractor's jobsite overhead costs will increase with the increase in duration of the project. Some of the contractor's HOOH will also increase.

If the contractor delays the work due to his own inefficiency or bad luck, the delay is not **excusable** or **compensable**. If the owner delays the work, it is excusable (the contractor is excused from completing on time by the amount of delay time that the owner caused) and compensable to the contractor. If the delay is due to causes beyond the control of either party, the delay is generally excusable, but not compensable [28, p. 227]. We should distinguish a delay, an event that causes an increased time of performance, from a **disruption**, which costs the contractor money, generally from inefficiency, but does not necessarily increase the contract time.

Types of contractor-caused delays are numerous and various [28, p. 232]. A short list of possibilities might include delayed mobilization, delayed submission of bonds, management problems, inadequate resources, failure to coordinate subcontractors' schedules, supply delays, untimely shop drawing submittals, inadequate labor force, and defective workmanship.

Of course, in a complex project, there may be several sources of delay occurring at the same time, called **concurrent delays**. Some of the sources of delay may be compensable and other not.

Acceleration costs include overtime, mobilization costs of extra personnel and equipment that are directly identifiable, and those that are difficult to identify that we discuss below under impacts. These costs are often associated with **crashing** an activity.

Field overhead, such as superintendent's salary, camp costs, office trailer and fence rental, and such are directly identifiable. HOOH, such as loss of opportunity to bid on new work because of lack of bonding capacity or interest on delayed revenue, are harder to identify.

C. Disruption and Impacts

There is some overlap in standard terminology regarding disruptions and impacts. Generally, disruption refers to the immediate and direct effect of a change on the rest of the contract. Disruptions are generally foreseeable. For example, a change requires the use of the only crane on the job, which had been planned for another use in the original contract. Either a second crane must be rented or the original work that required the crane must be delayed. "Disruption is the cost effect upon the unchanged work" [referencing Coastal Dry Dock BCA 23,324]. "Such proximally caused, foreseeable disruptions are sometimes called 'local disruption' [referencing Coastal Dry Dock].

Impacts are more distantly related to the change; for example, the same supervisor must now supervise the changed work in one location and the original work in another location. This "dilution of supervision" might be harmless to the job or might result in severe disruptions in the original work, depending on circumstances. Such impacts are genuine, but their effect is uncertain. Some authors divide impacts into "near impacts," which are akin to disruptions, and "distant impacts," which are not closely tied to the change in time or place. Multiple changes greater than those originally contemplated, but which do not alter the basic contract scope, lead to a ripple effect or to **cumulative impacts** of changes on work that is not changed, resulting in decreased productivity. The ripple effect is most often demonstrated in claims by showing an overall decrease in efficiency associated with changes; that is, the completed work and change orders cost more money than the contractor's original budget plus the price of the changes. Of course, the likelihood of both near and distant impacts increases as the number of change orders increases. Generally, distant or cumulative impacts are not "foreseeable."

D. Change Order as Release or Accord and Satisfaction

Once a directive for a change has been made clear and the owner and contractor negotiate a price and a change in completion date, depending on the wording of the change document, it may serve as complete **accord and satisfaction** for the change. That is, the contractor will be precluded from recovering amounts beyond those stated in the change. So presumably, the change to the contract price is complete payment for the change and all the effects of the change. If the changed work had an adverse effect or **impact** on original contract work (including previously negotiated changes), the contractor would not be paid extra for these impacts. Since impacts, especially distant ones, are difficult to foresee, contractors will hesitate to sign a change order if the impact of the change on other work and/or the completion date is uncertain. In addition, since owners and their legal council are well aware of this, they will often word the change order to be clear that, for the changed price, the contractor is accepting all the consequences of the change, including distant or cumulative impacts. On the other hand, the contractor may insist on language such as, "This change represents full and complete compensation for all direct costs and time required to perform the work set forth herein, plus the overhead and profit as provided for in the Change clause in this contract. The contractor hereby reserves the right to submit a request for equitable adjustment for all costs resulting from the impact of this change on unchanged contract work" [15]. As changes mount in a complex project, the impact of the changes becomes more and more difficult to foresee, suggesting that it is unfair to demand that a contractor agree to something that cannot be foreseen. On the other hand, the contractor is the party best able to control costs and the other effects of the change (or multiple changes), and thus efficiency suggests the contractor accept responsibility for the impacts. As we will discuss in Chapters Four and Five, these distant impacts are uncertainties that might or might not be amenable to risk-analysis tools, but need to be considered as uncertainties in pricing change orders.

E. Resource Constraints and Impacts

Related to impacts is the concept of resource constraints. Confronted with an accelerated schedule, the contractor can compute how many more workers will be needed to complete a project on schedule. For example, the contractor can assume that a doubling of labor on a task will halve the duration of the task. Often this is not practical, but even if it is, there may be other resource constraints. For example, an added night shift will share the same equipment, but if a rig breaks down, it will affect both shifts, and presumably, the chance of a breakdown is proportional to the operating hours. Often there is a shortage of equipment and maintenance facilities.

Another issue that makes it unlikely that doubling the workforce will double the production is the learning curve associated with the new shift. Often there are camp and logistic constraints. Skilled workers and experienced supervisors may not be available. There is a general decrease in productivity per manhour with overtime; there is also a loss of worker productivity associated with changed work. Redoing tasks is especially bad for the morale of skilled workers.

F. Causes of Changes (on Changed Work)

Differing site conditions (DSC) are a frequent source of changes. All modern government contracts leave the cost risk of DSC with the government. However, both the fact of the DSC and the cost are frequent sources of dispute. DSC claims are often divided into Type I, where the allegation is that the conditions encountered were different from those shown in the plans and specifications, and Type II, which alleges that the conditions encountered were unlike what a reasonable bidder would have expected. Finding rock where the entire job document indicated sand would be a Type I DSC. Finding a large boulder in an area where such boulders are not found, although the plans and specs do not indicate the soil type, would be an example of a Type II DSC. Usually, for a Type I DSC, the only issue is the cost, while for a Type II DSC, the contractor must demonstrate the fact of the DSC and then determine the cost. The point here is that, once a change order is accepted by both parties, it is still quite possible for the contractor to encounter a DSC on the changed work and thus need another change. While making bidders responsible for DSCs is generally against public policy and always a bad idea, the situation is somewhat different when negotiating a change order. Generally much more is known about the work during these negotiations than was known during the original bid. As well, it is possible to negotiate a lump sum for the contractor to assume a particular risk.

It is also possible for user-requested changes or third-party (often utilities) changes on the changed work, which would likewise result in a change to the change. Again, if the issues and risks are better defined, it is possible to pass these on to the contractor. If there are multiple contractors involved, the owner's failure to coordinate those contractors may result in a change also.

Design errors are a common source of changes to the original work. Likewise, there may be errors in the revised plans and specifications that are provided to the contractor as part of the change order process. "Contract documents are an imperfect expression of the design professional's and owner's intent for the project" [6].

G. Summary of General Risks Related to Change Orders

1. Not granting a change order, when one is due, may lead to constructive acceleration and a claim that may be difficult to defend. Claims may involve interest expense and legal fees.
2. Granting a T&M change order may result in loss of control of job costs and completions. Those risks are smaller on small changes.
3. Not granting a time extension, or failure to acknowledge an excusable delay, may result in constructive acceleration.
4. Using a unilateral change order may result in loss of control and a claim.
5. Not being aware of or failing to acknowledge the impacts resulting from a change order may result in a claim or an unconscionable situation.
6. Not being aware of or failing to acknowledge the cumulative impacts of multiple changes or altered situations on changes may result in a claim or an unconscionable situation.

7. The risks for 5 and 6 may be passed on to the contractor with proper contract language; see Chapter Five regarding contingencies.
8. The risk of DSC and changes from other sources, including design errors, user-requested changes, and third-party problems must be considered for the change.
9. Contractor risks from accepting a change order include delays, disruptions, distant impacts, and cumulative impacts.
10. Risks in Alaska include early freeze-up, morale, and personnel problems if projects are delayed into hunting season, and delayed R&R for supervisors and workers.
11. Lack of skilled personnel in general, and scarcity of those who will work in remote locations and/or far from families.
12. Shortage of warm, dry shop and storage space.
13. Risks due to over-commitment of senior supervisors, engineers, and estimators, and loss of bonding capacity.

Chapter Four: Uncertainty and Risk

A. Risk and Uncertainty
B. Probability
C. Risk Management – Basic Concepts
D. Quantitative Risk Analysis
   1. Deterministic estimates
   2. Non-deterministic to deterministic
      a. Expected value
      b. Range of values or beta distribution method
      c. Range
E. Non-Deterministic
F. Simulation Applied to de novo Estimate
G. Risk Analysis Applied to Forward-Priced Change
   1. Schedule and resources
   2. Impacts on other work
   3. Schedule
      a. Float
      b. Follow-on and resources
      c. Probabilistic nature of the entire schedule

A. Risk and Uncertainty

When negotiating change orders, we recognize that the owner is transferring risks to the contractor [27]. In order to determine a fair and reasonable price for the changed work, we need to determine what the risks are. First, we will digress from the common use of the word *risk*, which means liability or obligation, to the more technical meaning. *Risk* is the probability and severity of some event, presumed to be untoward or “bad.” (Some authors use the word *opportunity* as the opposite of risk, indicating the event would be beneficial.) Since we are often applying risk concepts to estimates, we will start by discussing risk in terms of cost estimating. The concepts can then be extended to issues related to scheduling and performance (quality).

Keep in mind that “estimates” are essentially guesses and often have a serious downside if they are wrong. The reason they are guesses is that there are future events (“states of nature”) that are uncontrollable, and these events will control the outcome. Regarding what we can say about these future events, there is a continuum, as illustrated in the following figure, taken from [29].

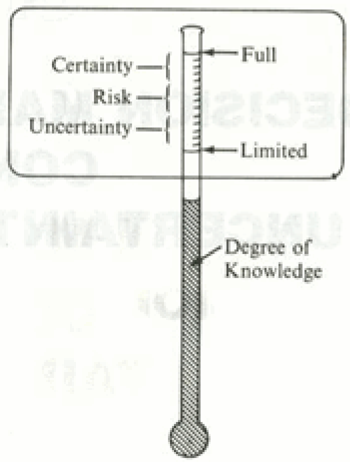


FIGURE 2–1. The Decision-Problem Continuum.

If we believe we have full knowledge of the future, we refer to a “certainty.” We might approximate certainty if we have a firm quote from a bonded subcontractor or supplier. Many estimating decisions are made under conditions of risk. In technical terms, *risk* means we feel we can state the probability of the events. For example, we know the price of concrete in the summer is likely to be $200/CY, but the price may vary by 15%. At the other end of the knowledge spectrum, we have *uncertainty*. We recognize alternate states of nature may happen, but we haven’t a clue how likely they are. Note the difference between the technical use of those terms and common usage. While the entire future is uncertain, if we feel confident about the probability of the future, we say there is *risk* and limit the use of *uncertain* to situations where we do not know the probability of events. Virtually all estimating decisions involve risk. We account for uncertainty with contingency; that is, things will happen (usually bad), but we don’t know what they will be or what they will cost. Contingency is often included in the profit line of an estimate.

Say we are building a road and plan to complete it before freeze-up. If we don’t complete the road, we will need to demobilize this winter and remobilize next spring—a costly matter. We can get climate records and determine the historical dates of freeze-up, and we can call the weather service and get an estimate of conditions this year. Using that information, we can state the probabilities of freeze-up by a particular date: “70% of the time we can work until October 1.” Thus, we try to quantify the risk of planning to work until October 1. On the other hand, there is a chance our key supervisor will quit, though having been with us for 20 years and having given no indication of dissatisfaction. Such events are uncertain, and we generally cannot estimate them. Thus, the freeze-up date is a risk, while the supervisor's quitting is just one example of a myriad of uncertainties.

Using this nomenclature, when pricing change orders, we will try to evaluate risks and price them. Uncertainties cannot be evaluated and must be accounted for in the contractors "profit," which in the case of change order markups will include HOOH and contingency/profit.

B. Probability

Since the concept of risk involves the probability of some harm, we need to spend some time discussing the meaning of that term. *Probability* means measuring uncertainties, assigning values to the uncertainties, and interpreting them. An important concept is that of a **random variable**. In the equation y = mx + b, if we know *m*, *x* , and *b*, then the value of *y* is known. The value of *y* is completely determined.

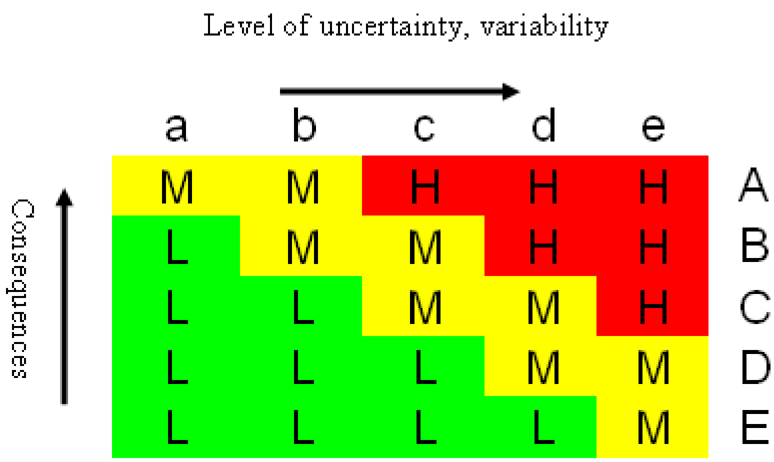
In the equation

$$Y = X*W \tag{1}$$

where *Y* is the cost of time lost due to rain next year, *X* is the number of rain days, and *W* is the cost of each day lost due to rain, the value of *W* is known, but the value of *X* is not known. If you know or can assume it, the value of *Y* can be calculated, but you cannot know *X* because it is a random variable. Another example involves throwing a die (one dice); the value on the upper face of the die is a random variable. You know the value will be 1, 2, 3, 4, 5, or 6, but you do not know which value will appear. Often in estimating costs or other future events, we will have an equation not unlike equation 1, with one or more random variables that we will need to evaluate and deal with in some rational way.

C. Risk Management – Basic Concepts

Before we delve into using probability to obtain estimate numbers, let us digress a bit into some general concepts of risk management as applied to estimating. Risk management proceeds in logical steps: risk identification, qualitative risk analysis, quantitative risk analysis, and risk response. Risk identification is a matter of identifying the variable that affects the estimate. Once variables are identified, qualitative risk analysis would categorize the variables into those that might be treated by contract language. Qualitative analysis also involves isolating the variables that do not vary much; for those, an expert opinion or estimate will be sufficient. For the variables that are likely to be both important and uncertain with high unpredictability, a quantitative analysis is warranted, using the techniques discussed below. Finally, risk response is the estimate with the uncertainty expressed or, in any case, accounted for. When considering candidates for transition from qualitative to quantitative risk evaluation, often an ordinal risk matrix, as shown in the next figure, is useful.



Example of an Ordinal Risk Matrix

Red represents high risk, for which much detailed planning and careful consideration of contract terms is warranted. A probabilistic risk analysis is probably warranted. Green represents low risk, for which the superintendent's or estimator's judgment is likely to be sufficient. Yellow represents moderate risk, for which some detailed consideration and use of analytical tools may be required.

For example, the level of uncertainty of a project would be graded from **a** = a firm quote from a reputable, bonded subcontractor, to **e** = worker-hour estimate for a first-time task that is unusually complex. The consequences would be graded from **E** = little impact to the firm or project, to **A** = reputation, bonding, or finances of entire company is in jeopardy. For example, in estimating the task of compacting a known soil using some new equipment with a new operator, we might judge the uncertainty as **c.** If the new equipment and operator do not work out, we can mobilize the old equipment for $10,000, so we might judge the consequences as **C**, categorizing the resulting risk as moderate. For such risks, the estimator or superintendent may exhibit more caution and try to gather more data than would be required for low-risk estimations. For high-risk estimations, concurrence of the home office would usually be required.

D. Quantitative Risk Analysis

Now we'll consider some details of the final estimate of a bid or proposal. All that follows in the next section could be said of planning estimates, rough order-of-magnitude estimates, etc.

Let me present an example: Although we can't tell the future, the bids are due by Thursday, and I must have a number for the installed cost of a wrought iron circular stair that the architect dreamed up. I've never seen such a thing, much less estimated one. Since that is only a small component of the project, my boss wants me to just provide "a number" that can be input into a spread sheet with dozens of other numbers. Since I am giving one number, it is called a **deterministic** estimate. Another way of looking at deterministic estimating is that we will convert one or several random variables into one number.

1. Deterministic estimates

A deterministic estimate gives one number for the item being estimated. This is also called a "point estimate," "most likely estimate," "precise estimate," and perhaps other names as well. My boss does not want a discussion of probability theory—just a number. I might arrive at the number in several ways. If I have experience with the item, I may have a number I am comfortable with that is simply my personal opinion or **expert opinion**. Often, when expressing a personal-opinion estimate, I will add something to my neat estimate, sometimes called a "factor of safety" or "lanyap" or some such cute euphemism. This addition may be conscious or subconscious. We have all discovered that the penalties for underestimating are much greater than the rewards for overestimating.

Sometimes estimates are made by a committee or "jury of expert opinion." Copious management research exists about such committee deliberations. Often a boss will attend the meeting, which brings up the dominating effect one person may exert on the committee. There are several methods, some known as "Delphi methods," of eliminating this effect. But when the committee is done, they will either give a number as a deterministic estimate, discussed above, or parameters to other estimates, our next topic.

2. Non-deterministic to deterministic

Next, we recognize that we are dealing with random variables and recognize that there are many possible outcomes. Because dealing with one number is simple, we will convert the random variable to a number. We discuss two methods: (1) expected value and (2) range of estimates or beta distribution method.

a. Expected value

If I know the probabilities of future events and the events are distinct and mutually exclusive, I can state them as such. Suppose several suppliers have issued qualified quotations, with a "while supplies last" caveat. I discuss this with the suppliers, and determine the probability that I will be able to use a supplier and the cost (see the following table):

	Probability	**Cost**	**P * C**
Supplier A	50%	$35	$17.50
Supplier B	30%	$40	$12.00
Supplier C	20%	$65	$13.00
Total	100%	Expected Value	$42.50

Note the probabilities must add up to one. Now I can go ahead and use the Expected Value, $42.50, as if it were a point estimate.

b. Range of values or beta distribution method

Another technique for converting probabilistic data into one number is the **beta distribution method**. While the expected value works best with discrete possibilities, the beta distribution method works well with continuous data. One uses an opinion, guess, or committee to provide three numbers by asking, "What is the highest/lowest/most likely cost of the item?" A good definition of "highest" is the number that you are almost/95%

sure will exceed the actual number, and similarly for the lowest. Those three numbers are then plugged into the formula

Point estimate = (Highest estimate + 4*Most likely + Lowest estimate)/6

Tests indicate that the point estimate derived this way is, on the average, better than just using the most likely number—or so the experts say. This formula uses the statistical function called the beta distribution.

c. Range

Before we go on, we have limited ourselves to getting "one number." I could have reported a range of values—usually just the highest and lowest—if that is what my boss wanted, but the principles would be the same.

E. Non-Deterministic

Non-deterministic estimating does not return a number, but gives a probability of certain numbers, such as, "I am 95% sure the cost will be less than $50," or "We are 60% sure the cost will be between $30 and $45." While such expressions of probable cost are tedious and seem fuzzy compared with "I estimate the cost will be $45," in fact the probability statement is the most accurate, while the precise estimate gives a false impression of certainty.

Let's say my cost estimate for the wrought iron circular stair has these components:

Item	Unit Cost ($)	Units (hr)	Extended
Buy stairs	$5000		$5000
Carpenter time	35	40	1400
Welder time	42	20	840
Painter time	32	20	640
Rent crane	120	8	960
		Total	$8840

We have a deterministic estimate of $8840. What are the chances it will cost exactly $8840? The answer is zero.

Now let's look at how we obtained these numbers. We called the wrought iron fabricator, who told us, "It depends on how busy we are and the material costs at the time you give us the order. It may cost anywhere between $3500 and $7000." For the trade people, I know the wage rate from the union scale and our computed burden, but how about the time. How long will it take to get the job done? I ask the carpenter supervisor who tells me, “It varies quite a bit. My guess is 40 hours, but it could take anywhere from 30 to 70 hours; 40 is my best guess.” The welder tells me, “I’m pretty sure I can complete the job in between 15 and 25 hours.” The painter tells me the same. The crane shop tells me they will charge me $120 if they have a crane, but if they have to rent one for me, it will cost double that. They do say there is only a 20% chance they will have to rent, this time of year.

From that input, I put together the table below. For each variable, I applied judgment to guess what I thought the best value might be, and determined the highest and lowest costs for each item. I return one number, but since it is made up of many guesses, how sure am I that the number is correct? What my boss and I do next depends on the competitive situation. Note that the difference between the lowest and highest number is $6600, and that either the high or low number could be defended.

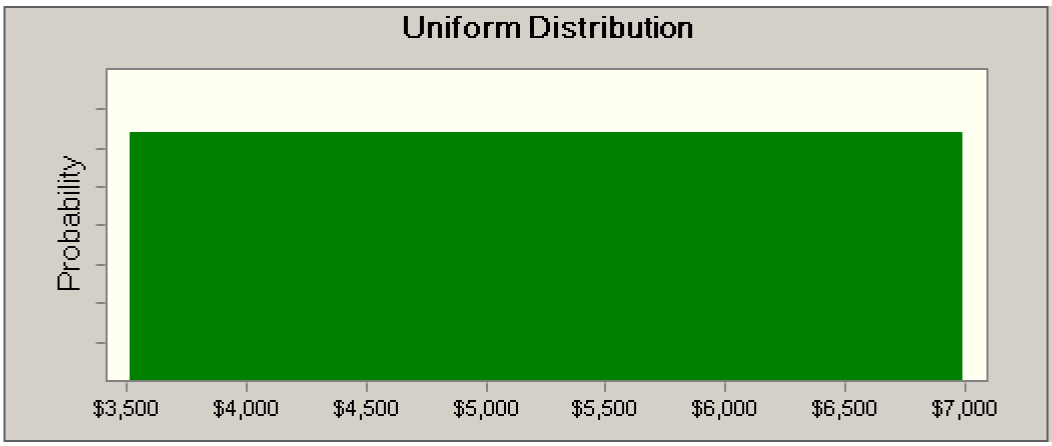
	My Guess			Low				High			
Buy stairs	$5,000	1	$5,000	Buy stairs	$3,500	1	$3,500	Buy stairs	$7,000	1	$7,000
Carpenter time	$35	40	$1,400	Carpenter time	$35	30	$1,050	Carpenter time	$35	70	$2,450
Welder time	$42	20	$840	Welder time	$42	15	$630	Welder time	$42	25	$1,050
Painter time	$32	20	$640	Painter time	$32	15	$480	Painter time	$32	25	$800
Rent crane	$120	8	$960	Rent crane	$120	8	$960	Rent crane	$240	8	$1,920
Total			$8,840	Total			$6,620	Total			$13,220

Next, I can input my guess, the high, and the low estimate into a beta distribution analysis. Point estimate = ($6,620 + 4*$8,840 + $13,220)/6 = $9,200. Note that I could have done a similar analysis for each item, and then added them.

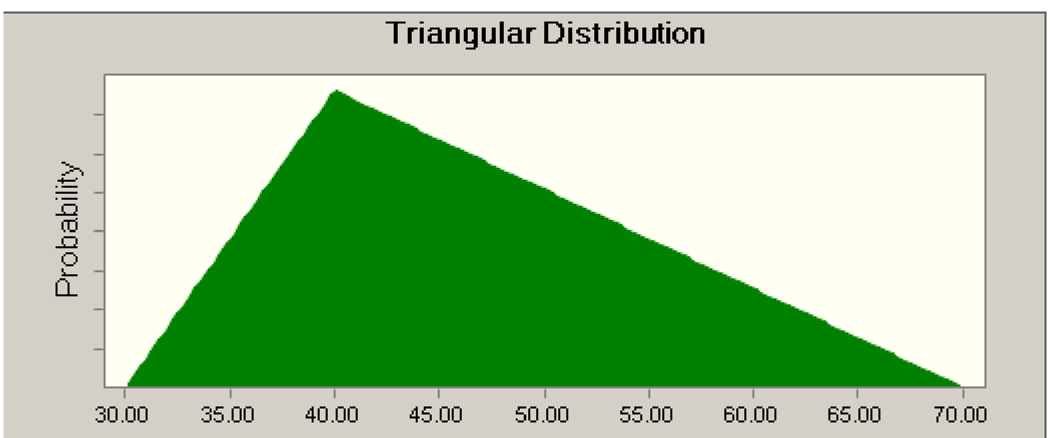
F. Simulation Applied to Estimate

A better analysis recognizes that each of the items has a factor that is a random variable, and we have some idea of the probability of the various values that factor might adopt. For example, the number of carpenter hours is a random variable. We put 40 hours into the estimate as if it is a definite number, but in fact, it is a random variable, not a definite number. Carpenter hours may have many values, depending on what happens in the future. What we can put into the estimate is a **probability distribution** that states the likelihood of each value of the random variable.

Let's consider the probability distribution of the first random variable, the cost of the staircase. The number can be anything between the two limits, and the probability is equal for all numbers within those limits. This is called a uniform distribution. Here is a graph of it.

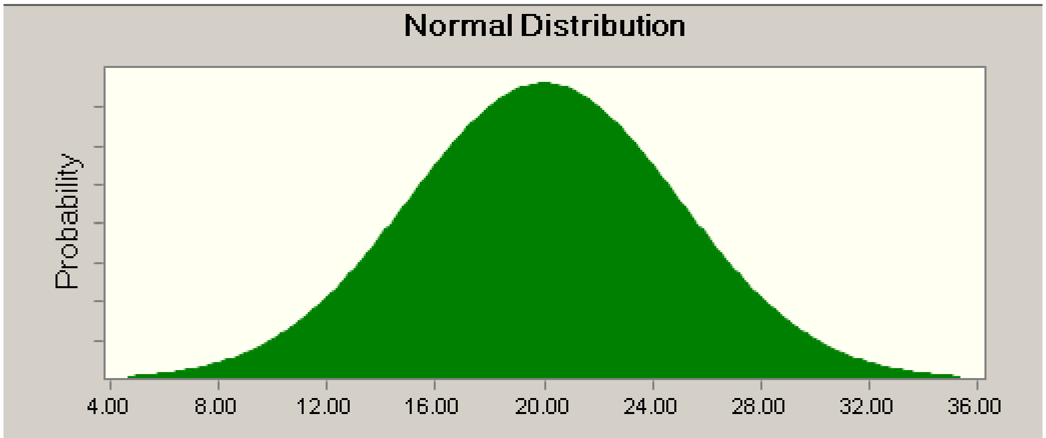


The random variable of the carpenter's time might be described by a triangular distribution. The carpenter gave us the least, maximum, and most likely times. Here is a graph of that:

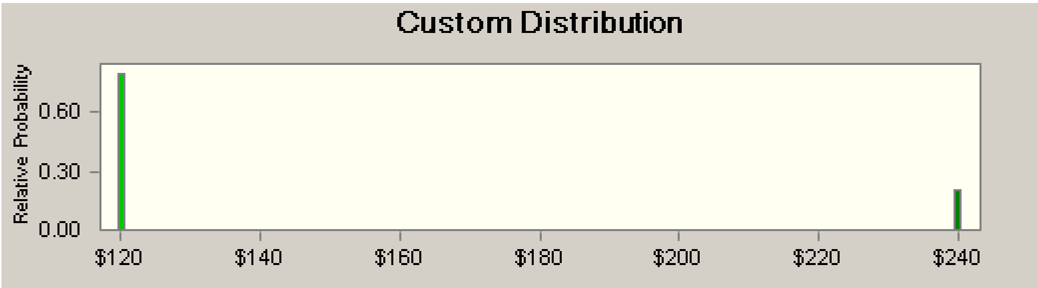


You don't see a scale on the *Y*-axis, but the scale will be such that the area of the triangle is 1.0, as is always the case with probability distributions. The area under the curve is always exactly one.

The welder's and painter's times are similar; they have given a range that they have some confidence in, but are by no means sure. Let's translate the "pretty sure" into meaning that they are about 68% sure that they will finish within those limits. Of course, there is some chance that it could be a lot longer, and for the moment, let's assume it could be shorter as well. The normal distribution or bell curve has the property that 68% is the probability within one "standard deviation" of the average. Let's approximate the welder's and painter's times as a **normal distribution**, with an average (or mean) of 20 hours and a standard deviation of 5 hours. About 65% of the area, that is the probability, lies between 15 and 25 hours, just as the welder and painter told us.

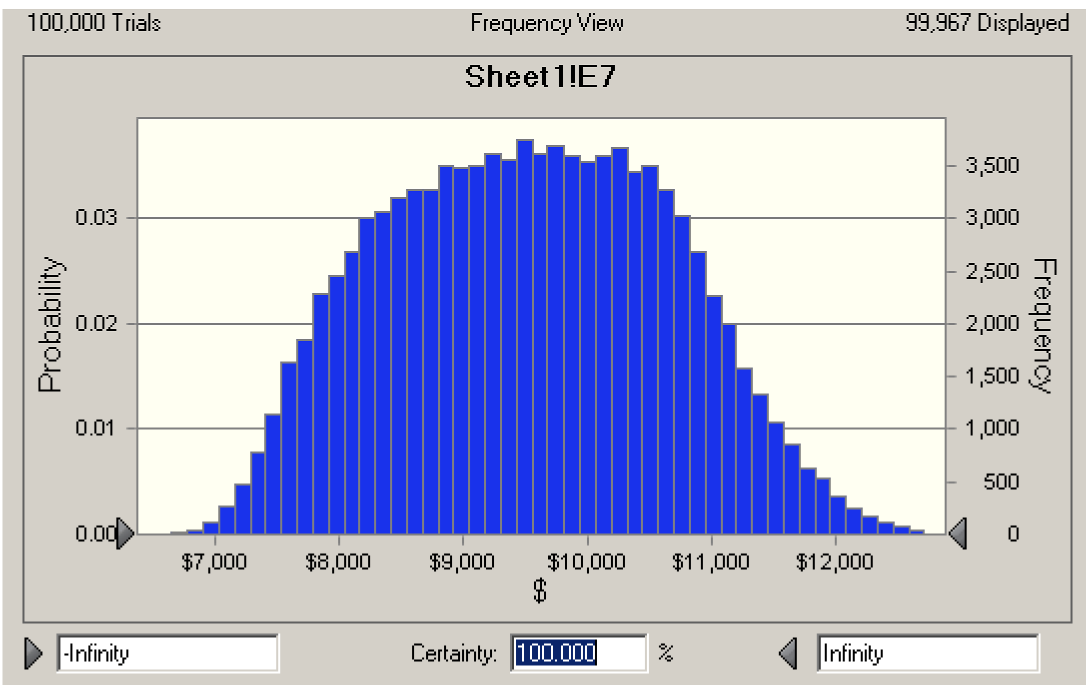


Finally, the crane cost has a percentage value. This figure is not a probability distribution; the chart below clearly shows that this cost will adopt one value 80% of the time and a different value 20% of the time.

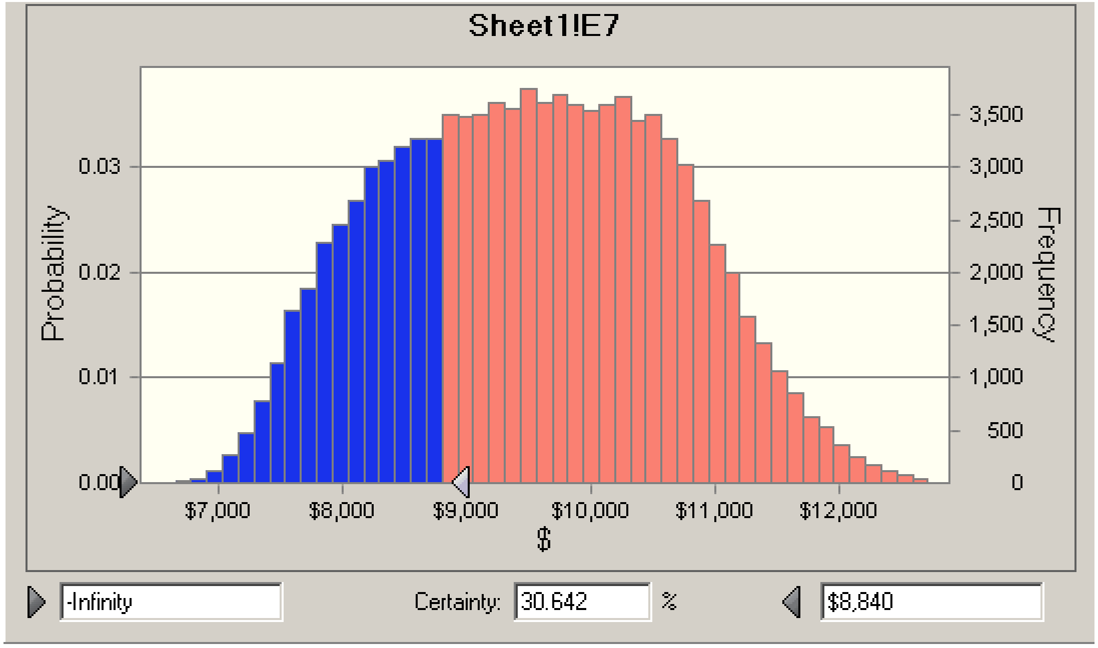


It would be useful to add these probabilities somehow, as we added the probabilities above in the expected value method. The problem is, that can't be done except in the simplest cases. What can be done is called "simulation," and the best-known simulation method is called the **Monte Carlo simulation**, which is a very powerful technique. Today, Monte Carlo simulations are easily done on your desktop with a program called Crystal Ball, an Excel-like program. What Monte Carlo simulations do is plug a random number into formulas that produce probability distributions of each random variable. This process is done for all the factors in your computation. If you only did this computation once, it would not make much sense, of course, but the simulation program does the computation thousands of times, and finally returns a probability distribution of the result.

Crystal Ball ran the simulation with 100,000 trials in a couple of seconds. Here is what the result looks like:

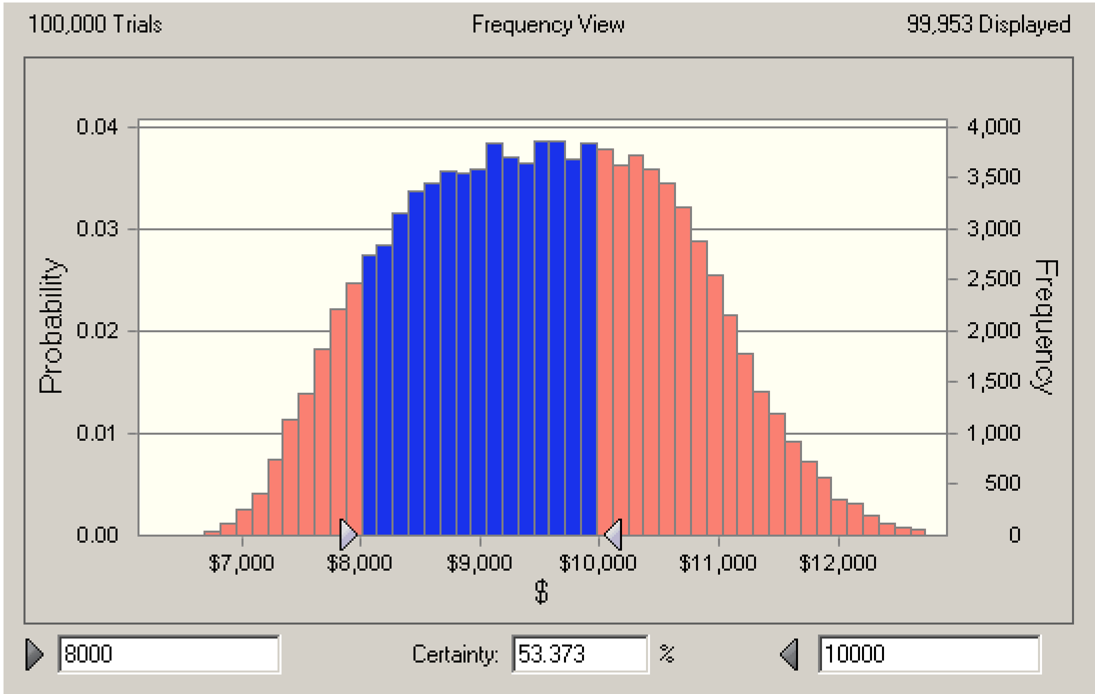


The result tells us that there is a 100% chance the cost will be between negative infinity and plus infinity, something you could have figured out without a computer. Now, however, I can ask the question, what is the chance the job will cost less than my original number of $8840?

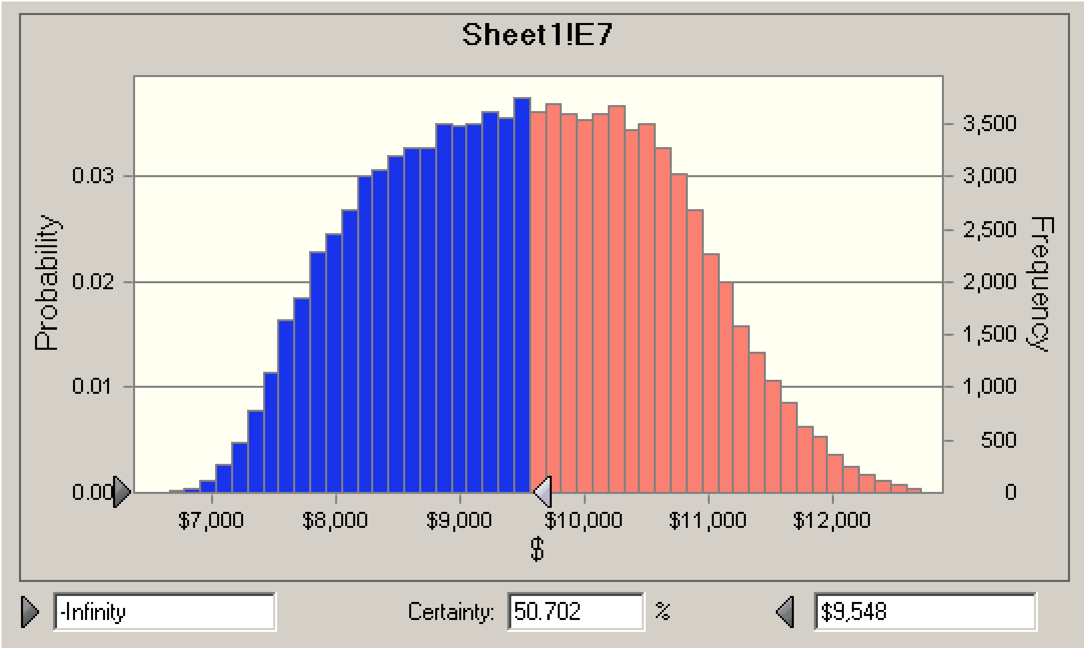


This result tells us that there is only a 30% chance that the job can be done for less than my original budget.

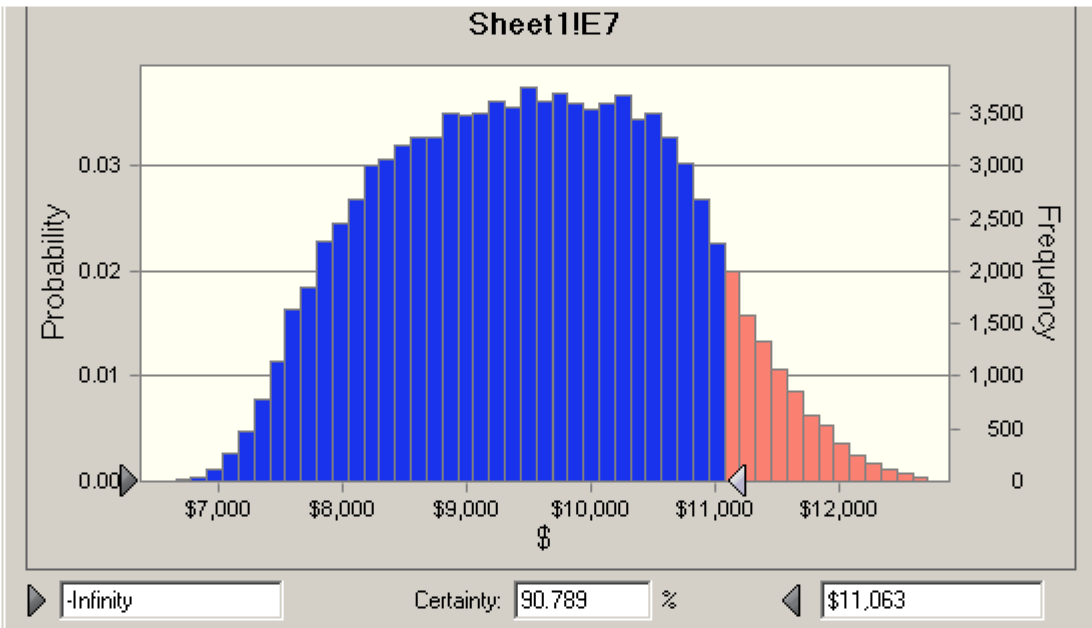
Crystal Ball lets me show a range of outcomes. For example, the figure below shows that there is a 53% chance the job will come in between $8,000 and $10,000.



The figure below shows us that, in this example, the 50% level is $9548; that is, there is a 50% chance the job will cost more than that number.



Finally, the figure below shows that there is a 90% chance that the job can be done for less than $11,000, but that means there is a 10% chance the job will cost more than $11,000.



In this example for painters and welders, I used normal distribution because it is familiar to most of you. While some tasks might seem to take forever (positive infinity), they never take less than zero time. But this theoretical problem using the normal distribution is generally not a real problem, since values that are very far from the mean seldom occur. There are many other probability distributions that start at zero, though, or you can set the start value. The “proper” way to set a start value is to find the distribution that best fits your data. We set a starting value for freeze-up date, since we have real data. Usually, however, when estimating productivity, we have only a few numbers, and they never describe exactly the same conditions that we are estimating.

Estimate Reconciliation

Can converting a simple concept—a point estimate—to a more complex concept—a probabilistic estimate—make things better? If “better” means simpler, it can’t, but if “better” means that the parties reach an understanding earlier, the answer is “probably.” Let’s look at all the numbers in one table:

Method	Number	% Difference from Point Estimate
Point Estimate	$8,840	-
Range Low Estimate	$6,620	-25%
Range High Estimate	$13,220	49%
Beta	$9,200	4%
50% Confidence	$9,548	8%
90% Confidence (less than)	$11,000	24%

We are tempted to look at the point estimate and consider it the "right number." If that is true, the beta and 50% confidence level are closest to being correct, but of course, the point estimate itself is unlikely to be correct. Note that the difference between the 50% confidence number and the 90% confidence number is $1500; the 90% confidence number is 15% greater than the 50% confidence number. Although I made the numbers up, they are not unrealistic, and the 15% difference between the 50% confidence level and the 90% confidence level seems realistic to me. An important concept in risk analysis of estimates, therefore, is to understand what level of confidence one is comfortable with.

Of course, real-life estimating has many complications not discussed above, such as level of estimate; basic, or summary; project stage; planning, rough order of magnitude; type of estimate; and labor and materials, cost factor. However, the non-deterministic analysis would be appropriate for estimating any of these.

Up to this point, we have only been talking about costs, not price, which includes overhead and profit. How about the risk? Should the allowance for risk be placed in the profit category, or should one place it in a separate category for contingency? (And what is our departure point for pricing risk: 50% confidence or 90% confidence?) We'll discuss these questions more in the next chapter.

G. Risk Analysis Applied to Forward-Priced Changes

Any of the methods presented above can be used to present risk in rational terms. Simulation is the most scientific of the methods. Several issues require more explanation, such as impact of a change on resources, impact on other work, and issues regarding scheduling.

1. Schedule and resources

Contractors often plan their jobs in two stages. First, they schedule and plan to optimize the production based on the nature of the work and the crew size and equipment needed. From that rough schedule, they "smooth" to optimize use of their resources. Next, they check to make sure the smoothed resources can accomplish the work. Finally, they base their estimate on the smoothed resources and duration. Let me give you an example:

Suppose that culvert installation would optimally require one crew of eight laborers for six weeks, and sign and guardrail installation would require four laborers for three weeks. The next step is to consider if a smaller culvert crew could do the work, albeit more slowly, and if a slightly larger sign and guardrail crew could be used. So the resource-smoothed plan might have six laborers for eight weeks on the culverts, and six laborers for two weeks on the signs and guardrails. Of course, that step requires an examination of the union rules and other practicalities of the work. Note in this simple example that total manweeks is the same. However, the maximum load on the camp would be reduced from eight to six (or twelve to six, if the original, rough plan showed the culvert and sign work taking place at the same time).

With small changes, the contractor's on-site staff can generally reorganize to absorb the change. If a change order will require extra people, a similar process must be used to determine optimal manpower and equipment, and then to smooth the resources. Hence, the details of how the schedule is changed will be influenced by two factors: the extra time needed to accomplish the additional work, and the need to smooth the resources to optimize use of crews and equipment.

2. Impacts on other work

There are two types of impacts on other work: direct impacts and indirect impacts.

Direct impacts (AKA disruptions) are generally obvious. For example, if a job has only one backhoe and the changed work will require another backhoe, the contractor must mobilize a second backhoe or use one for two jobs, perhaps negatively impacting both jobs.

Indirect impacts are often harder and sometimes impossible to identify. For example, if double use of one backhoe requires more mechanic time, or requires more supervision, the mechanic has less time to do preventive maintenance and the supervisor has less time to observe and supervise the other work.

These impacts were discussed in a legalistic way in Chapter Three. Here we mention them in order to estimate their probability and severity—their risk. Keep in mind that if one can isolate an effect, and estimate its probability and severity, a probability distribution of outcomes can be determined. However, many impact issues cannot be isolated. Further, the net effect of impacts is influenced by work on the original contract. This means that "normal" schedule changes in the original contract may influence the changed contract, but it can be difficult to estimate these influences. Insofar as the impacts can be isolated, though, the probability tools can be applied to them

3. Schedule

Three schedule issues should be mentioned here:

a. Float

Slack or float is the time an activity can be delayed without slowing or delaying the project. This is a useful concept. Activities with zero float are, by definition, on the critical path of the project. The opposite is more complex. If an activity that is not on the critical path is delayed, several things can happen. Using the slack in an activity does have a theoretical cost. The slack in activities is a form of contingency for the project, and using that slack decreases that contingency. For example, if an activity has a five-day duration and slack of five days, the activity can be delayed five days or can take twice as long to complete, without threatening the overall schedule. However, if some of those slack days are lost and delay occurs, the project will be delayed.

b. Follow-on and resources

A follow-on activity may be delayed. While this would not delay the project either, the change in the follow-on activity may cause a resource problem. For example, a problem would arise if the follow-on trade was electrical and the electrician was scheduled to go to another job. Another issue involves the "stacking" of trades, that is, scheduling different trades into the same location at the same time.

c. Probabilistic nature of the entire schedule

The duration of an activity is probabilistic in nature. While beta evaluations yield an estimate of overall project duration, in fact, the uncertainty of durations may lead to changes in the critical path. (Note: CPM schedules that use beta distribution for input are often known as PERT schedules. Appendix C presents an example.

Chapter Five: Negotiation Guides

A. Introduction
B. Basic Change Procedures
C. Evaluating Contractor's Estimates – Basic
    1. Cost
    2. Schedule
    3. Resources
    4. Performance, production
D. Evaluating the Risk Element – Basic
E. Evaluating Interference Issues
F. Extraordinary Issues
G. Profit, HOOH, and Contingency
    1. Profit
    2. Return on investment and HOOH
    3. Contingency in estimate of individual change
    4. Contingency in profit for distant (indirect or cumulative) impacts
    5. Summary of profit, HOOH, and contingency
H. Other Risks to be Considered

A. Introduction

This chapter assumes that the reader has some experience with negotiating change orders and following basic DOT procedures and standard specifications. However, we will present some basics with the purpose of framing the risk issues in context. We will track a change through the system, emphasizing the component or risk in the change and evaluating that risk. It is vital to understand the negotiation process as a matter of transferring the risks to the contractor and compensating the contractor for assuming those risks.

Here we suggest

- Reviewing the general estimate and the submitted cost estimate
- Examining the basic estimate with risk (probability tools)
- Examining risks related to conflicts and interferences between the change to the work and the original contract
- Examining risks related to extraordinary items
- Reviewing the job risks versus profit

B. Basic Change Procedures

The following are some questions that the owner's project manager should ask:

Is the situation a change? Will it become a constructive change? This is, of course, a standard issue. If the owner's representative determines it is not a change but the contractor insists it is, the owner's representative must examine the likely costs to the contractor resulting from a constructive change. If the owner handles the issue as a change, the owner may be able to negotiate a favorable price for all the risks due to disruption and impacts. If the owner does not agree that a change is warranted and the contractor is later able to persuade the claims-review process that the situation should have been a change, the owner risks bearing all the costs of inefficiency and delays.

Have we identified the change? That is, have we described it accurately and completely in changes to the contract documents? Are other related changes likely and/or differing site conditions likely? If there are likely to be other related issues, a T&M change may be needed. A T&M change can be quite efficient if the contractor and owner are cooperating in good faith and diligently keeping records. The risk of T&M inefficiency is well known. Here we need to review the possibility that the T&M change will interfere with the original contract. Below we discuss how a forward-priced change can interfere, but a T&M change can also interfere, and it is more difficult to negotiate the interferences. We cannot suggest any specifics, other than that the owner's representative should examine the possibility that the T&M work will interfere with other work. If interference is possible, the contractor will want to charge those disrupted original work items to T&M, and this may be difficult to administer. When a definable piece of the original contract is deleted and a T&M change is substituted, a deletion of the cost of the original work should be offset against the T&M charges. Since T&M has an overhead and profit greater than the contractor had on the original work, owners will generally ask for the offset to include overhead and profit. Contractors may disagree on this point; hence, some negotiations may be required even for a T&M change.

It is generally not good practice for owners to pass on the risk of DSC to contractors in the bidding. However, a change order is negotiated and the owner and contractor generally have a better notion of the subsurface conditions. If an alternative for the subsurface or other unknown conditions can be identified, is it practical to negotiate alternative prices, depending on what is encountered?

Can we stand to extend the contract completion date? From the owner's perspective, what are the risks of a completion later than the planned date? Some of these risks might be public safety if temporary routes must be used, costs of owner's project office, and political and public relations issues. Here we suggest using an ordinal risk matrix to make qualitative evaluations of the risk, similar to the matrix shown in Chapter Four, using the probability of harm on one axis and the severity of harm on the other axis. This may make clear which risks are important enough to analyze in detail and mitigate if the contract is delayed.

C. Evaluating Contractor's Estimates – Basic

1. Cost

We want to identify all the items in the change that are likely impact costs or schedules. Ideally, we want to examine risk in two ways: first, what are the probabilities of the various outcomes, and second, what is a fair price for the contractor's assumption of those risks?

The contractor should have an estimate based on labor and equipment needed for each activity. These have some relationship to unit prices, but if the change can be handled by bid unit prices, not much analysis is needed. Here we assume that the unit prices are not used. The change needs to be examined in relation to the original estimate, with a determination made as to what extra labor, equipment, etc., is needed to accomplish the change; and what changes need to be made to the original schedule.

Often a contractor will embed contingency into a change order estimate (see discussion in Chapter Four). This may be based on specific risk issues, or it may be simply related to the confidence the contractor must place in the estimate—say 90%, compared with the owner's confidence, which may only be 50%. This embedded contingency relates to the profit markup. If it is high, the allowable profit should be lower. However, if the embedded contingency is recognized, it can be accounted for in the risk analysis.

If the contingency is related to a specific item, it may be better, and is certainly more logical, to examine the item with respect to its risk, using the probability tools.

When examining the estimate, keep in mind the general variability of cost categories; labor is most variable, operated equipment is next, while installed equipment and subcontracted items are low. (Of course, in this discussion, if the subcontractor's work were the subject of the change, the subcontractor would be evaluated as a general contractor.). Jobsite overhead is generally a function of project duration; however, see note in interference discussion below.

We begin with the estimate, either as a separate estimate or as an increment, and organize it via the **Work Breakdown Structure (WBS)**. There are many variations on WBS format, but generally work activities are listed as row labels on the vertical side, and organizational resources or cost categories are listed as column headings on the horizontal side. For each resource, there is usually a unit rate and time. Examine the unit rate, labor by type, or equipment; check the Blue Book rates; and note if adjustment factors are used properly. If yes, both the labor and equipment rates can be considered fixed, and the variability will come from estimation of activity durations.

Note the effect of overtime. If a standard overtime rate is used and the job is of several weeks' duration, it is usually convenient and proper to use an average rate that accounts for overtime. See below for some issues.

The next question involves the variability of the estimated time as it affects costs. Here, for each individual item, if it was your own estimate, you could use the beta method (you need a pessimistic, most likely, and optimistic value) or expected value (you need the percentage probability of each of several outcomes.) If these values are part of a negotiation with the contractor, however, you must be able to communicate effectively regarding them. What may be the most effective approach is to simply ask the contractor to express which of the WBS items are both uncertain (in the common use of that word) and important, and then translate that expression to the risk tools. These deterministic methods yield a precise estimate for each item, or they can be expressed as parameters for later input into a probability model.

2. Schedule

The next step is to look at the effects of change on the project schedule and determine if an activity is on the critical path or directly affects activities that are. If so, the schedule must be adjusted, and the estimate adjusted for increases in job overhead for the extended duration. Since these changes in duration are often related to the increases in labor or equipment time, the same probabilistic tools that were used in labor estimating can be used. The scheduling program, **MS Project**, allows input of the beta parameters directly. We discuss a more complex case below. Not all scheduling uncertainty relates to labor and equipment. Weather, barge deliveries, and shipment of special-order items may likewise be uncertain and may delay the project. Simulation using an electronic spreadsheet may indicate different critical paths (see Appendix C).

3. Resources

Generally, it is expedient to assume that the current resources are sufficient for the project, reschedule the work, and then examine the resources. Determine if the resources can be smoothed without altering the schedule or if the schedule must be rearranged. If resources constrain the organization, decisions can be made to mobilize more resources, and that change can be costed. The concept of "learning curve" (see Appendix C) may be needed if new crews and first-line supervisors must be brought to the job. Again, mobilization costs (or crashing costs) or the need for resources can be examined using probability tools. These may be best examined with an expected value approach (see Appendix C).

4. Performance, production

Generally, production relates directly to the labor and equipment estimate, so it need not be considered separately. However, there is often a risk element relating to quality assurance and change orders. That is, if the produced work does not meet quality standards, it will need to be reworked. This is especially true if the changed work is novel. Here the risk could be examined as an issue in duration of the labor and equipment, or a risk related to the novelty of the changed work and possibly a component of the learning curve (see Appendix C). The seriousness of the "fix" also needs to be considered. For example, consider the difference between an extra day of rolling versus chipping out defective concrete from a bridge abutment, replacing the rebar, reforming, and re-pouring.

D. Evaluating the Risk Element – Basic

If the estimate had many smaller items and most of the risk issues related to standard or common variations in production rates, then deterministic tools, expected value, and beta distribution could have been used. At this point, the change estimate would be reduced to one number. If there were major items that were uncertain, there may be several estimates (or major components of the estimate) with a result something like this: "The cost will be $120,000 if we can get enough material out of Pit A, but will cost $200,000 if we must get half the material out of Pit B." Since the practical definition of "get enough" will depend on the contractor's equipment and skill, it is reasonable to transfer some of the risk to the contractor. Here the expected value could be used, with negotiations focusing on geological reports and the probability of finding enough material in Pit A. An alternative approach would be to negotiate a change that has two unit prices, one for using Pit A and one for using Pit B. Note that care would be needed in the unit rates so that there is no incentive to use one pit or the other, unless the intention was to give such an incentive.

E. Evaluating Interference Issues

Above we analyzed the situation as if the change and the original contract were largely separate, but in reality, they seldom are. Therefore, we now must examine the effect of the change on the original contract and the entire project. Change orders cause disruption or near impacts to the existing work, which should be foreseeable; they also cause distant impacts or, in the case of multiple change orders, cumulative impacts, which are not foreseeable.

Here is a list of typical disruptions (AKA direct impacts), generally proximate to the changed work in time and location:

1. Lack of work space. Overlapping trades. Work area congestion.
2. Sequencing and buffer times. One trade or activity must precede others.
3. Demands on a small pool of skilled labor. Tendency for remote work to stretch existing crews rather than mobilize new crews. Needing skilled workers at the same time on the changed and unchanged work.
4. Work on change forces interruptions of original work, learning curve
5. Out-of-sequence work.
6. Lack of camp space.
7. Decrease of manhour productivity with extended overtime.

8. Shortage of mechanics and maintenance facilities.
9. Increased supervision and engineering time, dilution of staff.
10. Dilution of line/field supervisors working on changed and unchanged work being done at the same time.
11. New planning and re-planning, meetings.
12. Learning curve, quality control (QC) issues pertaining to novel work or situations.

If there are several changes, the owner must consider the effect of indirect or cumulative impacts (AKA ripple effect). Such an effect may not be proximate to the changed work in time and location. Here we use the terms *indirect impact* and *cumulative impact* synonymously because their effect and the chief issues are the same. Although neither is foreseeable, after they have happened, indirect impacts might be separated into individual cost items, while cumulative impacts refer to the synergistic disruptive effect of an unreasonable number or unusual kinds of change orders when the sum of the impacts exceeds the individual disruptions caused by each individual change [15]. In such cases, causation is hard to prove, since even when disruptions are initially caused by owner-directed changes, the contractor is able to reduce or escalate disruption and inefficiency due to the project management factor. Clearly, some contractors are more skilled than others are in handling multiple changes and disruptions, but all are dependent on job conditions, equipment, and so on. Below in the profit and risk section we will revisit changes and disruptions. For now, it is important to realize that they occur and to determine whether the risks for cumulative changes can be passed on to the contractor. Careful wording of the change order can do this, but the contractor will want to be compensated. Since possible changes are really uncertainties, and since we don't know their probability, compensation should be by contingency in the profit line, rather than risk in the cost lines.

F. Audit Issues

Indirect or cumulative impacts are difficult to audit. That is, in a T&M or unilateral change, it is straightforward to keep track of the direct costs. Indirect impacts are difficult to assign to the change.

G. Extraordinary Issues

Often the risks of a change order are more or less standard variations in estimates of time and effort required to complete the work and/or the amount of that work that should be ascribed to the change. However, sometimes there are singular or at least unusual issues that bear on the fair price for changes. Here we will discuss two:

Seasonality – Alaska's extreme climate forces most horizontal construction to end when the soil freezes. Some vertical construction can continue with proper "closing in," but horizontal construction cannot. The date of freeze-up is uncertain, however; early freezes occur sometimes, followed by warm spells when work can continue. Historical temperature records are available from the weather service, from which one could compute the dates when it is possible to work in 90% of the years, 50% of the years, etc. This analysis would provide some logic to discussions about how long work can go on.

Transportation Delays – An analysis should be used to determine if the delay is incremental or complete. *Incremental* means the delay is due to a shipment that is received a few days late, and the delay becomes worse if the shipment is later. *Complete* means that the shipment either gets here this year or does not. For incremental delays, beta or expected value can be used. Judgment applied to the shipper's promises may result in the use of an expected value, such as there being a 10% chance that the shipment will not get here until next year.

H. Profit, HOOH, and Contingency

1. Profit

The profit line of the change order **markup** will contain three items: return on investment, HOOH, and contingency. Contingency is a more complex issue, since it regards uncertainties and risk.

2. Return on investment and HOOH

In the federal contracting methods discussed in Chapter Two, we saw that a "standard profit" was 3% to 7% of the costs in a job with low-risk parameters. An allowance for HOOH is put in the estimate as a cost before that profit is added. HOOH is auditable, but for our discussion, let us assume it is 10%. Thus, a standard markup for return on investment plus HOOH might be 13% to 17% for a low-risk job. Compare that to San Francisco Bay Area contractors, where the bid markup, which includes some risk, is 10% to 12%. However, for negotiated change orders, a markup of 13% to 17% is probably fair for an estimate with no contingency. Compare this with allowed T&M markups for state DOTs, which also do not contain contingency and are approximately 17% to 25%. When contractors bid work, they use a percentage markup, which is discoverable if the issue gets to court, but until then, could be regarded as a trade secret. Generally, a certain loss of bonding capacity and definite bid opportunities might be direct costs to the job, while the possibility of such losses would be accounted for in the profit and the firm's financing structure via the HOOH allowance. We note that the profit from a change order is likely to be too low to offset the loss of profit on a future job, but on the other hand, the successful bid and profit on the future job is speculative. A related factor may be change in market conditions. There are more jobs to bid on in some years than in others, and the contractor's margin rises; the opposite happens if there are fewer jobs to bid.

HOOH is auditable. If cost and pricing data are required as part of the contract, total HOOH can be estimated fairly closely. However, the allocation of HOOH to any particular project or change within that project is stretching the data too far. Although such allocations are simple, they are fraught with theoretical difficulties and generally are not worth the effort. Thus, including HOOH in the profit is justified.

The issue of "spread" in the initial bids should be mentioned here. Research has shown that if the low bidder leaves a lot of money on the table, more changes will occur [10]. This can be interpreted in two ways: the contractor may have knowingly bid low and then tried to "make it up with changes," or there may have been a lack of clarity in the bid documents, with different interpretations of the contract by the bidders.

That leaves the question of how much should be added for contingency for the change order. Of course, that is a matter of judgment for the owner's representative and a negotiating item for the contractor. Here we present two methods for logically approaching this issue. A key item for either analysis is how much "fat" there is in the original estimate. We assume we started with a "neat" estimate, neither fat nor lean. This is what skillful owner's estimators or outside consultants should produce for the neat estimate—if they consider all the cost items.

3. Contingency in estimate of individual change

First, we examine the embedded contingency, using probability tools. Consider that we completed the entire estimate and entered all the risk items into Crystal Ball, and received an output similar to that shown in Chapter Four. If each item were estimated neatly, that is, no contingency was added to each item, a 50% confidence level would be the best theoretical estimate. However, the contractor should not accept this, since it means a 50% chance of losing money. The contractor should propose an amount equal to 90% confidence level, which is achieved another way by using the 90% confidence levels in line item estimates.

4. Contingency in profit for distant (indirect or cumulative) impacts

The contingency in profit for distant impacts depends on the contractor's willingness to accept all risk from indirect impacts due to the change—that is, not to qualify his price. If we have included the risks of local or direct impacts in the cost items, we still need to negotiate a fair amount for the risk that the contractor assumes from indirect impacts.

a. Adverse cost impacts

Below we present a qualitative risk table that indicates job factors that are likely to increase the risk of indirect or cumulative impacts. Since this analysis is quite subjective, there is no point in trying to convert it to quantitative data. It can be used, however, in conjunction with the owner representative's judgment. For example, one could count the number of low, medium, and high scores, and thus help characterize the probability of indirect impacts.

Table of Adverse Cost Impacts

	Probability of Adverse Cost Impacts		
	Low	**Medium**	**High**
Timing of Changes	Early in Project		Late in Project
Changes as a percentage of original project	Small, less than 25%		Large, greater than 50%
Total number of changes	Small		High
Is the design engineer close-by, readily available?	Yes		No
Overall project size	Small	Medium	Large
Is overtime needed to meet revised schedule?	No	Some	Much
Is over-manning-new crew needed?	No	Some	Several
Are change orders and **RFIs** processed quickly	Yes		No
Problems with worker morale, labor relations, absenteeism, turnover likely?	No		Yes
Owner's team on job since the start?	Yes	Moderate turnover	Recent
Are several of the changes complex and unfamiliar?	No	One	Several
Are a number of changes coming late in the project?	Early		Late

b. Allowance for indirect impacts

Having evaluated the likelihood of indirect or cumulative impacts, what is a fair allowance for them? One approach would be to examine the general contingency and risk factors in the DFAR estimates, noting that a general factor for risk is 6% to 9% of the job. Of course, that is for the whole job. In a negotiated job, on the one hand, most of that risk has been accounted for by the probabilistic analysis of changed line items in the estimate.

On the other hand, in a large multicomponent estimate, over- and under-estimations are likely to average out, while for a change order, the risk of a mis-estimation is larger. Saunders [5] identifies a large public owner that offers a bonus of 10% for forward-pricing a change.

Thus, a reasonable approach to evaluating the risk of indirect and cumulative impacts is to allow 6% if the subjective evaluation indicates a low probability of significant impacts, and to allow up to 15% if the evaluation indicates a high probability of significant impacts.

Note several items:

1. The nature of these indirect impacts is that they are not foreseeable. We can only judge their likelihood in a very general way, based on factors. If they were foreseeable, they could be estimated in a direct line of the estimate for the change order.

2. This percentage is applied to the change order, which may be a small portion of the project. One could postulate a small change that has large indirect-impact consequences, but the unforeseeable nature of indirect impacts makes it impossible to evaluate the probability and severity of such. Both the large and small indirect impacts are equally uncertain.

3. This approach is predicated on a neat estimate to start with, at the 90% certainty level.

4. Although the indirect impacts are unforeseeable, it is likely that the contractor will be in the best position to manage and minimize these when they arise. It is to the owner's benefit to transfer this risk to the contractor.

5. If a T&M change is utilized and indirect impacts arise, the contractor has every incentive to ask for a new change or extend the T&M to the impacted work.

5. Summary of profit, HOOH, and contingency

Assuming that the cost estimate was neat and the 90% confidence level of direct costs was used, a 13% to 17% markup accounts for profit and HOOH. If auditable numbers are available, these should be substituted. Depending on an analysis of risk factors for indirect and cumulative impacts, a contingency allowance of 6% to 15% would be added.

I. Other Risks to Consider

1. In negotiations with contractors, it is vital that the owner's representative negotiate with their own organization and the users and other vital stakeholders prior to or concurrent with negotiations with the contractor. (These in-house negotiations are often the most difficult negotiations.) If the owner's representative and the contractor reach an agreement, but this is later rejected by others, frustration mounts and trust is weakened, and further negotiations become more difficult—and, of course, the clock has been ticking and time constraints may become tighter.

2. An important pre-negotiations topic among the owner's organization, users, and stakeholders is the cost of not finishing on time. These costs may be so great that large cost increases are justified in order to finish on time, or they may be minor, and the schedule can be allowed to slip with little justification of a cost increase. It is important in such pre-negotiations that the concepts of risk and the variability of outcomes be explained to the stakeholders.

3. It may be important for the owner to examine the owner's costs and the risks to the owner's costs allocated to the project. An extension of the project to following years may increase the owner's overhead without increasing the owner's allocation of project costs, especially if a percentage of costs is used.

4. At some point, if negotiations bog down, the owner may need to consider the costs of not forward-pricing the work. That is, the owner may need to consider either completing on a T&M payment method or deleting from the current contract the section of work that includes the change—including the change (as well as the risks from that switch) in a future competitively bid contract. If the changes are easily separable from the main work, T&M changes can be administered more efficiently or the work can be deleted. Usually, however, the change is not easily separated. Given reasonable supervision of a T&M contract, the cost might not be significantly different from a forward-priced change. The greatest risk comes from delays or problems with the modified contract that are not easily separable from the original contract. In such a case, disputes are likely

about charging time to the various activities; and delays to the overall project are likely to be blamed on the change, again making disputes likely.

Appendix A: Acronyms and Glossary

Entries below note the first time the word is used or discussed by use of square brackets.

A,B,C

Accord and Satisfaction [discussed on page 27].

AKA. Shorthand for *also known as*.

AK DOT. Alaska Department of Transportation.

AUTC. Alaska University Transportation Center http://www.uaf.edu/ine/AUTC/AUTCindex.html .

Average cost [discussed on page 18]. For mass produced units, it is the total cost of the production divided by the number of units produced.

Bar chart [21]. A simplistic schedule that show the scheduled start and finish of major activities, but not their dependence.

BCA, Board of Contract Appeals, any one of several boards that must hear a federal contracting appeal, before it may go to federal court.

Beta distribution [discussed on page 45]. Sometimes called "range of values method."

Blue Book [16]. A standard guide with rental rates for construction equipment. See reference [25] for general information, but the book is proprietary and a subscriptions is needed to access the guide.

Bonds and bonding [17]. A guarantee by a financial institution that one party to the contract will perform. Bonds are required for most government contacts. "Bonding capacity" refers to the contractor's ability to obtain bonds, usually based on the contractor's financial status and reputation.

Burden (salary) [discussed on page 14].

Cardinal change [discussed on page 31].

Compensable (delay) [discussed on page 34]. Same as excusable delay.

Concurrent delays [discussed on page 35].

Constructive change [discussed on page 32].

Contingency [4, discussed on page 67]. An allowance in estimates for "unknown unknowns."

CPM critical path method [20]. A scheduling method that indicates the dependence of various activities on other activities. Contrast with bar chart.

Crashing (the activity) [discussed on page 20].

Crystal Ball [50]. A computer program that runs in MS Excel and performs simulations, see Appendix D.

Cumulative impacts [discussed on page 35 ff]. See ripple and indirect impacts.

CY. Cubic yard.

D,E,F,G

Deterministic estimates [discussed on page 44].

DFARs. Defense Federal Acquisition Regulations.[25]

Direct impacts (AKA disruptions) [discussed on page 35].

Direct job costs [12]. Cost that the company would not have incurred, if they did have the job in question.

Disruption [discussed on page 35].

DSC. Differing site conditions [discussed on page 6].

Economy of scale [discussed on page 19]

Eichlay formula (pronunciation: ike lay) [discussed on page 23].

Estimated quantities [30]. In a unit price contract, these are the amount of each unit that is included in the initial bid; same as “Plan quantities.”

Excusable delay [discussed on page 34].

Expected value [discussed on page 35]

Expert opinion [discussed on page 44].

Fat estimate [13]. Includes embedded contingency; contrast with a “lean estimate” that is so called because the estimator is not confident the work can actually be accomplished for the price.

FICA. Social Security

Field overhead [discussed on page 35].

Fixed costs [discussed on page 18].

Float [discussed on page 20]. Same as slack.

Force account [27]. Sometimes used synonymously with T&M, but T&M refers to a payment method, while “force account’ refers to the owner’s right to use that payment method.

G&A. General and administrative [25]. Same as HOOH.

Goodwill [discussed on page 14].

H, I, J, K

HOOH Home office overhead [23].

Horizontal (heavy) construction [15]. Roads, airports, and other civil works, frequently equipment intensive.

Indirect impacts [discussed on page 55].

Impacts [discussed on page 35].

Jury of expert opinion [discussed on page 45].

L, M, N, O

LSM. Linear scheduling method (see reference 26). A method of organizing work that has (usually) linear distance on one axis and time on the other. Activities are shown as lines that relate location of activities at particular times.

LD. Liquidated damages [34]. Contract clause that penalizes the contractor for each day a project is late.

Monte Carlo simulation [50]. A method of simulation that uses random numbers to determine the probability distribution of several random variables.

Markup [62]. The difference between project direct cost and the amount billed.

Marginal cost [discussed on page 15].

MS Project [62]. A scheduling program (see Appendix D).

Neat estimate [discussed on page 13].

Normal distribution [46]. A probability distribution with the parameters mean and standard deviation. See http://en.wikipedia.org/wiki/Normal_Distribution

P, Q, R, S, T

Party, Parties (to a construction contract) [4]. A person or business with a direct interest in the contract. "Third parties" may be affected by the contract, but are not directly involved in it.

PERT. Program evaluation and review technique [57]. Basically, just a CPM schedule with the activity durations inputted as beta distribution parameters.

Plan quantities (see "estimated quantities)."

Probability distribution. It describes the likelihood of random future events http://en.wikipedia.org/wiki/Probability_Distribution

PM. Project manager [9].

QC. Quality control [64].

R&R, Rest and Relaxation, i.e., time off, generally away from the remote jobsite.

Range of values method. Same as beta distribution method.

Random variable. An unknown quantity whose value is random. http://en.wikipedia.org/wiki/Random_Variable .

Ripple effect [2, described on page 32].

Release (see accord and satisfaction).

RFI. Request for information [68]. A communication from the contractor to the owner asking for some information, typically a clarification about the plans or specifications. Often the first step in a formal change order process.

RFP. Request for proposal. [7]

Slack [20] (see float).

T&M. Time and material. [1]A contract payment method, where the contractor is paid for his costs. The contractor does not give a firm price in advance.

Type I and II Changes [34]. Terms from federal contracting law regarding DSC. A Type I DSC change means the plans and specifications indicate something that was not true, while a Type II DSC means the condition was something that a prudent contractor would not have anticipated.

U, V, W, X, Y, Z

Unit price contracts [22]. Contract bid at a definite rate per unit of work and an estimated amount of units.

Vertical (building and most industrial) construction [15].

WBS**.** Work **b**reakdown **s**tructure [61]**.** An organization for managing projects. The total project is broken down into activities**,** with resources assigned to each activity. Activities may be subdivided into subactivities, and so on.

Appendix B: References

A good general reference book about construction administration:
Construction Project Administration, Eighth edition, by Edward R. Fisk and Wayne D. Reynolds, Pearson/Prentice Hall, Upper Saddle River, New Jersey (2006). Especially:

Chapter 11, Risk Allocation and Liability Sharing
Chapter 19, Changes and Extra Work
Chapter 20, Claims and Disputes.

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Appendix C: Examples

1. Expected Value
2. Beta Method
    a. Cost
    b. Schedule
    c. Beta Method, Beta PERT, Beta Distribution
3. Resource Constrained
4. Probabilistic Methods

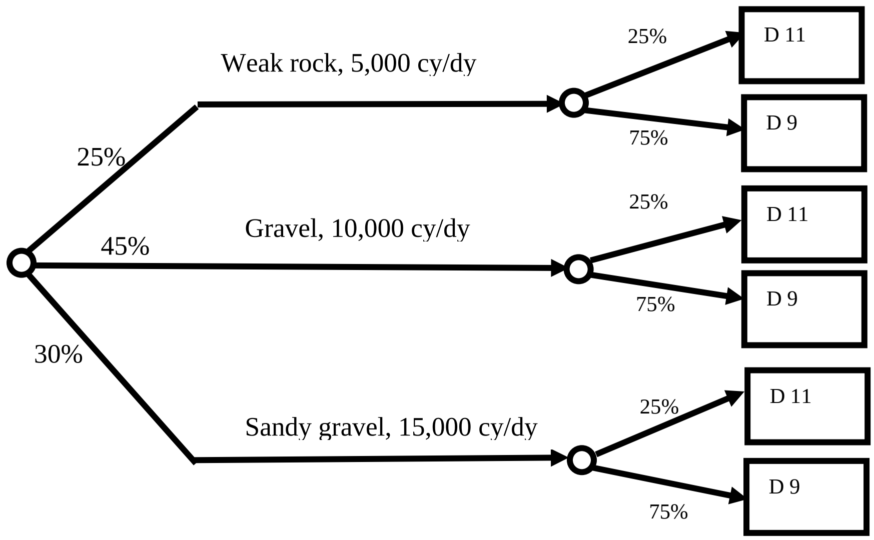
1. Expected Value

We need to barge a load of steel from Seattle. The freight cost will be $5,000. If we miss the barge sailing, we will need to truck the steel, and that will cost $20,000. If we feel there is an 80% chance we will make the barge, we could do an "expected value" analysis as follows:

$$\$5,000 * 80\% + \$20,000 * 20\% = \$8,000$$

and put that number in our estimate.

Using a "decision tree," the same process can be used for problems that are more complex. Here we will use production rates. There are three types of soil that we may encounter—weak rock, gravel, or sandy gravel—with typical production rates of 5,000, 10,000 or 13,000 CY/day. We estimate there is a 25% chance we will hit weak rock, a 45% chance we will hit gravel, and a 30% chance we will hit sandy gravel. If our high production D11 dozer is available, we can increase thoses rate by 35%. However, there is only a 25% chance we can get that dozer. What should we put in our estimate for a production rate?



Material	Rate (cy/day)	p	Equipment	p	Increase rate	
Weak rock	5,000	0.25	D11	0.25	1.35	438
Weak rock	5,000	0.25	D9	0.75	1.0	938
Gravel	10,000	0.45	D11	0.25	1.35	1,575
Gravel	10,000	0.45	D9	0.75	1.0	3,375
Sandy gravel	13,000	0.30	D11	0.25	1.35	1,365
Sandy gravel	13,000	0.30	D9	0.75	1.0	2,925
				Expected Value =		10,615

Commentary

Let's consider a case where there is one large item under negotiation. An owner's engineering mistake has caused a major delay in fabrication of a bridge section in Seattle. If the revised pieces can be loaded on a barge by a certain date, the shipping cost will be $10,000 and there will be no project delays. If the pieces can't make the barge, they must be trucked and the cost will be $40,000, plus there will be a 7-day delay. The owner and contractor are negotiating the change, and both agree that there is an 80% chance the bridge pieces will make the barge and a 20% chance that they will need to be trucked. From the above expected-value analysis, the cost would be 80% * $10,000 plus 20% * $40,000 = $16,000. The delay would be computed at 20% of 7 days = 1.4 day. An alternative approach is to negotiate a contract change stating that cost to the owner will be $10,000 if the bridge pieces make the barge and $40,000 plus a 7-day extension if the pieces need to be trucked. Which is better?

Clearly, with the contract alternate method the owner bears all the risk, and the contractor bears none of the risk. And while we appraised the risk as 80-20 on the day we negotiated the change, as time goes on, the contractor is in the best position to alter the situation one way or the other. If the contractor will get some extra profit plus a 7-day extension that might be used if there are other problems not related to the bridge, the contractor has no incentive to use his entrepreneurial skill to reduce the possibility that the bridge pieces will have to be trucked.

On the other hand, since we assumed the contractor's best estimate on that day, which we agreed was 80-20 if we negotiated strictly with the expected value result, the contractor has no incentive to choose this method. All the risk is being passed to the contractor. Although the contractor now has an incentive to use entrepreneurial skill to make the barge, no extra compensation is being received to do so.

Clearly, the contractor should ask for something more than the expected value as compensation for that risk, which was not there prior to the change. How much is fair? One approach is to look at the profit the contractor would make if the unit were trucked. Presumably, although we are negotiating the entire price, we will agree on a profit markup based on the cost of the change order—say it is 10%. Thus, the profit on the barge would be $1,000, while the profit on the truck would $4,000. If we agree to the expected value, the profit would be $1,600. If we agree to allow $4,000 profit on the expected value cost, we would be compensating the contractor an extra $2,400 ($4,000 – $1,600) to accept the risk. That is, his profit percentage would be 25% ($4,000/$16,000) rather than 10%. Of course, we simplified even this hypothetical analysis by neglecting the risk of delay.

2. Beta Method

a. Cost

Gathering input into the beta distribution analysis is similar in practice to gathering information for a probabilistic analysis using the triangular distribution. We ask an expert, say our carpenter supervisor, how long it takes to compete a task. The answer may be something like, "It varies quite a bit. My guess is 40 hours, but it could take anywhere from 30 to 70 hours, but 40 is my best guess." From that we use the formula to determine an estimate of (30 + 4*40 + 70)/6 = 43.33 hours.

b. Schedule

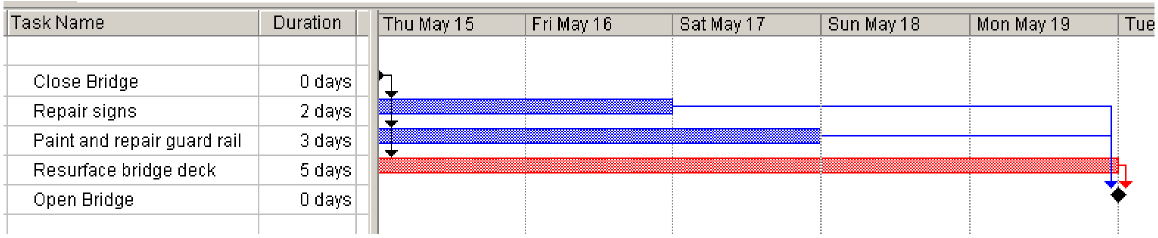
The beta distribution is used in PERT scheduling, which is just standard CPM scheduling with the input for durations expressed as lowest, most likely, and highest. MS Project has an input screen that allows input of those numbers directly. While beta/PERT makes use of some probabilistic concepts, it is not probabilistic scheduling, really, since once the three input numbers are entered, value becomes deterministic. This may be important if there are alternate critical pathways, a topic we will consider next.

c. Beta Method, Beta PERT, Beta Distribution

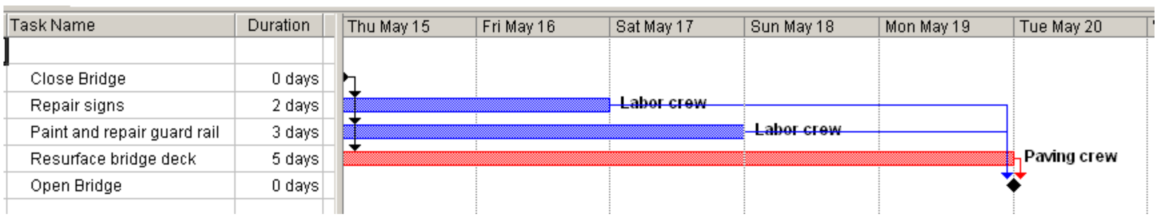
What we call the "Beta Method" and what is commonly called the "Beta PERT" have their logic in the probability distribution of statistical theory called the beta distribution. Actually using the statistical beta distribution in our analysis to too complex, and for practical purposes, the result is close enough that it would not pay to learn more about the actual beta distribution.

3. Resource Constrained

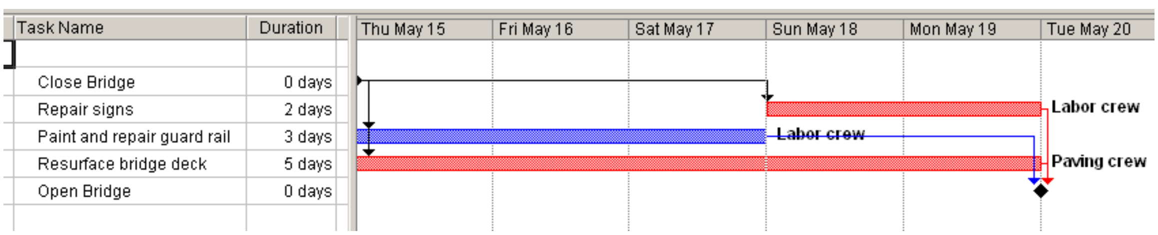
Suppose we are resurfacing a small bridge deck. The contractors schedule has three activities:



This is the activity schedule, and all three activities are apparently independent. The longest—resurface bridge deck—is the critical path, indicated in red. However, when we look at the resources needed, we find that there are two crews with different skills and equipment: a laborer/painter crew and a paving crew. Here's the schedule with those resources noted:



Of course, the contractor would not have two labor crews, so the next step is called resource leveling. This is the "leveled" project:



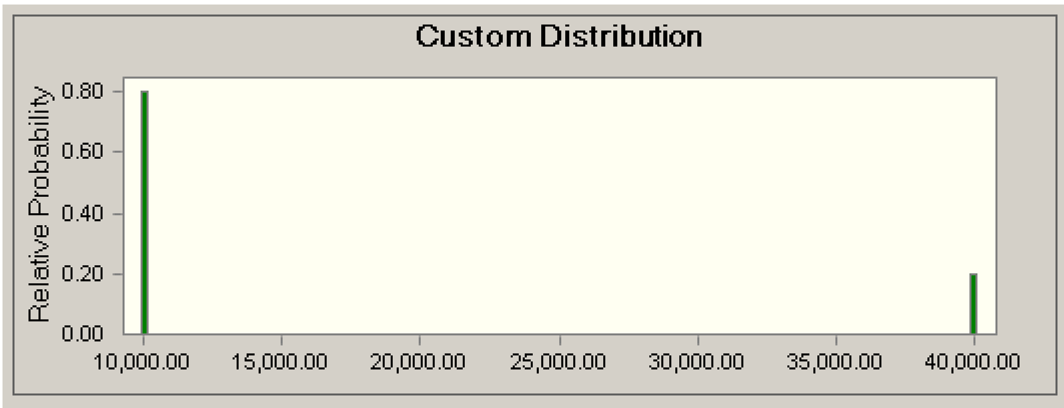
This was done automatically with MS Project, and an artifact of that program makes it appear that the repair signs activity with the labor crew is critical, while the paint and repair guardrail activity is not. The point is that now, with the resources leveled, there is no slack in the two activities that seemed to have two days and three days of slack in the schedule that was not constrained by resources.

In a complex project, there may be several resources that need to be considered in leveling, and choices must be made. The first step is level within the available slack, and is generally not too difficult. However, if after that process there are still resources that are overcommitted, a management decision must be made as to which tasks to delay or crash in order to level the resource and/or increase the resource. For example, if the project has one crane, and it is needed on a bridge at one end of the project and as a clamshell at the other end of the project at the same time, some alteration in the schedule is needed or a second crane must be mobilized.

The point here is that when risks are being evaluated, in addition to delays in the schedule activities that must be evaluated with the CPM, the effects of schedule alterations on resources must be considered.

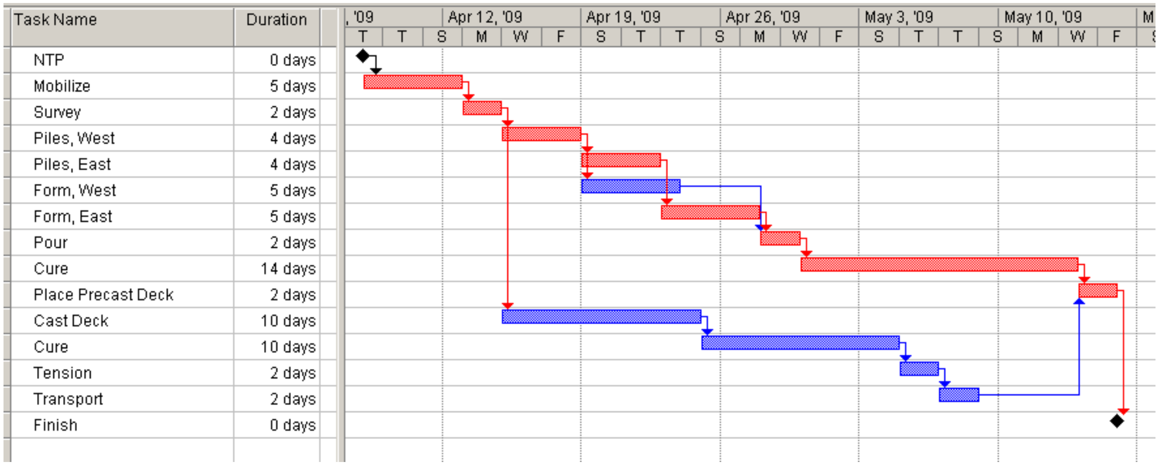
4. Probabilistic Methods

In Chapter Four, we gave an example of using Crystal Ball simulation to evaluate the probabilities of a cost estimate for a circular stairway. If we had one major variable, we could use the expected value beta method to arrive at one number. If we have many variables, a simulation using Crystal Ball is often accurate. If for one of the variables, we have two or several numbers for which we know the probability—for example, the 80-20 split—there is a function in Crystal Ball that lets us input that to the spreadsheet.



Above is how the barge/truck estimate would be input into Crystal Ball. However, sometimes there are major branches in the estimate, each that have their own set of random variables. These, too, can be handled in Crystal Ball by using an "IF" statement in Excel to send the estimate down one path in one set of circumstances. We will illustrate this with an example about scheduling.

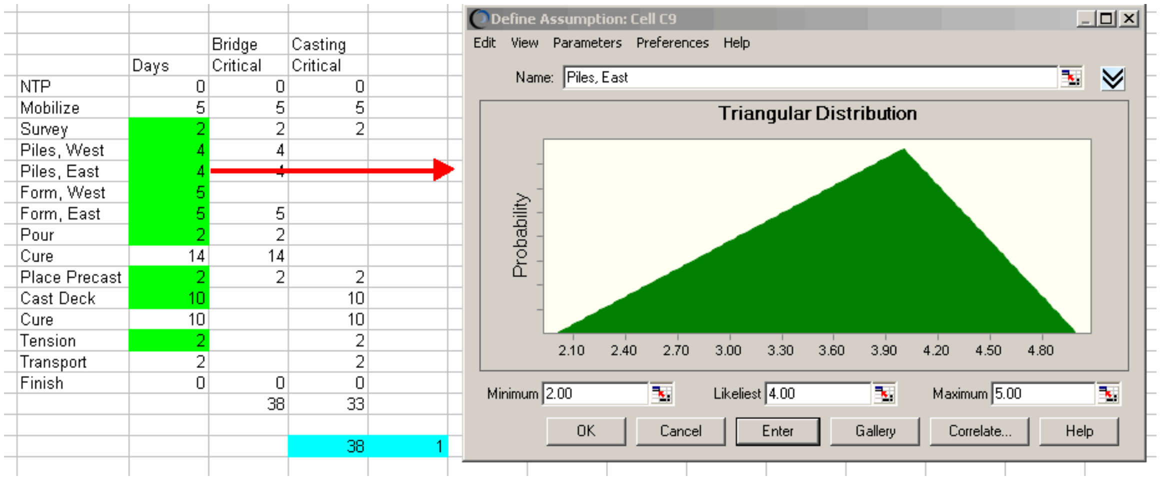
The project is a simple bridge with precast decks. Precasting cannot start until the survey is complete. Note that there are two main pathways—the bridge piers and the precasting—and they diverge after the survey and join at the setting of the bridge deck. Let's assume that most of the tasks have a probability distribution that can be modeled as a triangular distribution, but that the casting of the deck must be modeled as a uniform distribution from 5 to 20 days, depending on how busy the yard is when the survey is complete. We can see by inspection that the critical path will change if it takes more than 15 days to cast the slabs, since there are only 5 days of slack on the casting branch of the schedule.



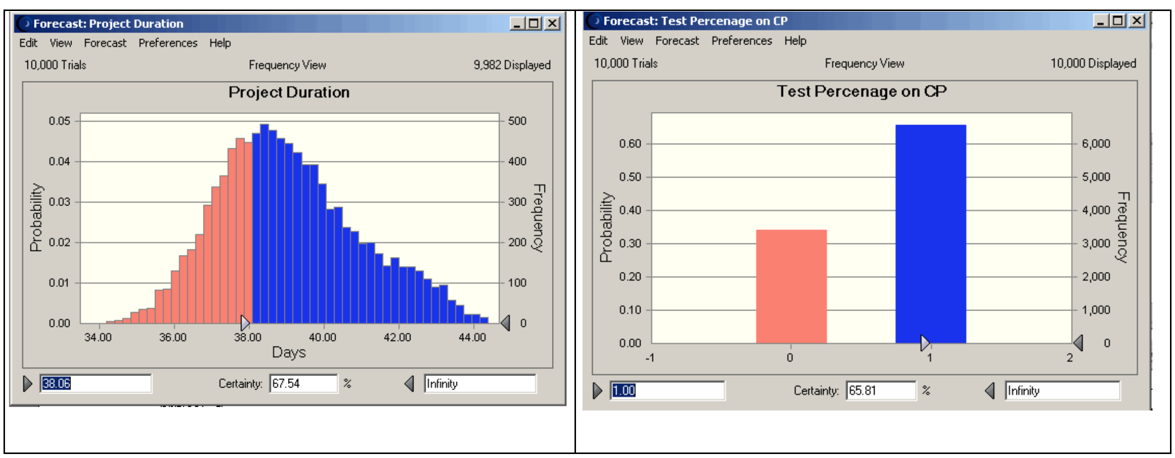
Here are the input parameters to Crystal Ball:

		Triangular		
	Lowest	Likely	Longest	
NTP	0	0	0	
Mobilize	5	5	5	
Survey	1	2	2	
Piles, West	2	4	6	
Piles, East	2	4	5	
Form, West	4	5	7	
Form, East	4	5	6	
Pour		2		50% 2, 50% 3
Cure	14	14	14	
Place Precast Deck	1	2	4	
Cast Deck	5	10	20	Uniform
Cure	7	7	7	
Tension	2	2	3	
Transport	2	2	2	
Finish		0		

All are triangular distributions, except pouring the supports that is 50-50 one day or two, and casting the deck that is a uniform distribution. After loading the probability distribution into Crystal Ball, we recognize that Crystal Ball will throw random numbers into the green ("assumption") cells according to the distribution. So we establish alternate paths: one for the current critical path via the bridge preparation and one if the casting is critical.



Shown above is a typical triangular distribution. The first blue cell has an IF statement that directs the program to use the larger of the two values from the summation cells, which have 38 or 33 in them at this point. The second blue cell, which currently has a 1 in it, is a counting cell that will be a 1 if the bridge was critical and a 2 if the casting was critical.



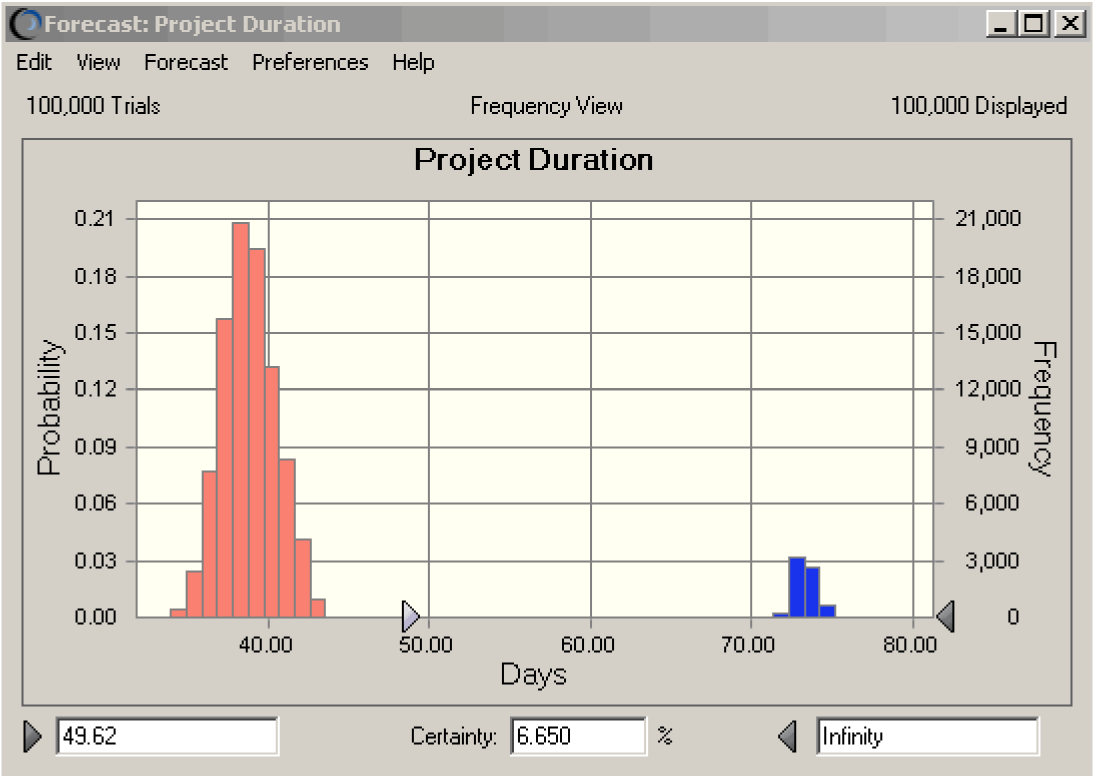
This arrangement lets us see that 67% of the time the project will take more than 38 days, and 35% of the time, it will be the casting that is the critical path.

As shown in the basic schedule, transport of the slabs will take place on 7 and 8 May. Suppose there are load restrictions, such that heavy loads cannot be transported from 15 May to 15 June. We recognize that if the transport does not start by the 14 May, the casting will be the critical path and the project will be delayed until after the load restrictions are lifted. The probability of this can be determined with a slight addition to the Crystal Ball Excel sheet by adding a column of running total of project days. Here we'll just track the casting. Next, we count days and realize the transport has to start on day 38. If the date is not made, the earliest that transport can start is 15 June, 31 days later, so we put in an IF statement that puts the value of 69 (38+31) in the running total, if the transport does not start until day 37.

	A	B	C	D	E	F	G	H
1					Casting			
2			Bridge	Casting	Running			
3		Days	Critical	Critical	Total			
4	NTP	0	0	0	0			
5	Mobilize	5	5	5	5			
6	Survey	2	2	2	7			
7	Piles, West	4	4		7			
8	Piles, East	4	4		7			
9	Form, West	5			7			
10	Form, East	5	5		7			
11	Pour	2	2		7			
12	Cure	14	14		7			
13	Cast Deck	10		10	17			
14	Cure	10		10	27			
15	Tension	2		2	29	29		
16	Transport	2		2	31			
17	Place Precast	2	2	2	33			
18	Finish	0	0	0	33			
19			38	33				
20								
21				38	1			
22								
23								

=IF(E15>38, 69, E15)

=IF(C19>E18,C19,E18)



In the "Forecast: Project Duration" screen above, we see that while the probability of the casting being the critical path is the same—about 35%— there is a 6.6% chance the project will be delayed until after the road restrictions are lifted.

The number 6.6% means that you are 93.4% certain that the bridge deck will be transported before the road restrictions. In most science, 95% is considered "near certainty," since 100% certainty is never possible. Of course, here we are only presenting possible inputs into negotiations that will have many other inputs.

Appendix D: Software, Crystal Ball, MS Project, Prima Vera