Contingency Analysis
(Putting the guess work to work)

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Introduction

The term Contingency is described in many different ways with the common theme of accounting for the unexpected. As Cost Engineers we describe a contingency as “An amount added to the estimate to allow for changes or project cost growth that experience shows will likely be required.”[1] Contingencies are also described as events that may and may not occur[2]. How then can we budget or create estimates for such mythical events? To complicate matters we can not include events in our contingency analysis that might happen under Murphy’s Law (what can go wrong will go wrong), that are acts of God, or that are the result of a change in scope. So were do we start.

As indicated in most Cost Engineering handbooks we can begin with past experience. Those of us not advanced enough in years to appreciate a good slide rule will have to depend on modern databases and the experience of our mentors and senior estimating staff for historical guidance. Cost Estimators have been developing contingency costs for estimates, budgets, bids and so on, since the beginning of time. These estimates depended on the experience of the estimator and his ability to relate past projects of a similar nature to the current estimate. Today, we depend heavily on the use of mainframe computers and PC's for the bulk of our analytical needs, but we still continue to rely on rule-of-thumb and experience as our estimation guides. Still there is more to Contingency development than trying to determine the cost of unforeseen events. We also need to assess the Risk associated with the contingency, based on the type of estimate we are developing.

For purposes of discussion, the Department of Energy’s (DOE) rules and procedures for cost estimates will be referenced throughout this paper. The DOE has a rich source of information available on the subject of cost estimating and contingency analysis and thus provides a good basis for discussion.

Contingency Overview

The need to develop what is known as a contingent cost is necessary in the analysis of most project cost estimation to account for unexpected events in the project lifecycle. The contingent cost will depend greatly on the type of estimate being developed. As

Cost Engineers and Estimator we deal with three primary types of estimates: Order-of-Magnitude, Budget, and Definitive Estimates. Every estimate has bits and pieces of information that are either missing or unavailable at the time of estimation. The larger the hole, the greater the risk. The key component is RISK. Our clients will often expend millions upon millions of dollars on a project, but initially they will assess a projects cost, potential, and risk. Thumbnail sketches and napkin approximations of project costs will usually not include any sort of risk analysis. However, as the project matures, our clients will be more and more interested in the amount of risk they are taking on. Additionally, their banks and financial backers will be very concern about the project risk.

Our job as a Cost Engineer is to estimate the project cost and assess the project risk as it relates to our estimates. The risk examined in cost estimating is primarily made up of two components profit and contingency. The risk associated with profits relates to the probability of making a profit on the job. The contingent cost portion of the risk is related to our ability to accurately estimate the cost potential cost overrun on the project due to unforeseen events.

The less we know about a project the greater the contingent cost thus the greater the risk. So why bother. If we load our estimates with detail from quantity take-offs and eliminate all the unknowns we have no need to address contingent cost. Unfortunately, in many cases the cost to complete such detailed estimates would outweigh their value. Time and money are typical constraints when developing cost estimates. Instead of wading through detail that would take time and cost plenty we employ analytical methods to summarize the detail into manageable quantities and assess risk in the form of contingent cost to account for the lack of detail. This approach may seem lazy and unethical on the surface, but in reality it is a more sensible and practical approach.

Contingency Analysis Considerations

The applications of contingencies cover the life a project. Considerable latitude is typically give to estimators in the application of contingencies, however, it is imperative that all assumptions and basis for the contingency are clearly documented. Initially, there are many complicating factors to consider in a Contingency Analysis including the project complexity, the design completeness and status, the market conditions, special conditions, assessment level of uncertainty, technology, equipment availability, environmental conditions, waste disposal and management to name but a few. However, by far the most important aspect of a contingency analysis is the data.

Our analyses of contingencies are very dependent on the type of estimate we are trying to prepare. If, for example, we are developing an Order-of-Magnitude estimate, the contingency estimation we use will typically be very high due to the lack of detail available for the estimate. Since Order-of-Magnitude estimates are based on limited information and rely heavily on our experience and creativity, the estimates will vary considerably[3]. Definitive Estimates, on the other hand, are deemed as complete estimates and will likely carry smaller contingent costs because of the high level of detail in the estimate. Put simply, the less detail available the higher the risk, the more detail available the lower the risk.

The amount of detailed information available to us is highly dependent on our client's needs. If our client is just fishing for a number, on a cursory basis, to determine if further pursuit of a project is merited, then a detailed cost estimate is probably not necessary nor is a contingency based risk analysis. However,if we are working as a subcontractor for the Department of Energy (DOE), every cost estimate we create is expected to have a contingency component as part of the analysis. Estimates and their contingencies will vary from industry to industry. What is important to one group of clients is trivial to another. The DOE, for instance, has specific guideline for its estimating procedures whereas in another industry every estimate received would probably not resemble the last.

For construction development and control the DOE outlines four specific types of estimates: Planning/Feasibility Study Estimates, Budget or Conceptual Design Estimates, Title I Design Estimates, and Title II Design Estimates[4]. Each type of estimate has a specific purpose and basis. Each estimate has a specific set of requirements, guidelines, and degrees of accuracy. As an example, a Planning/Feasibility Study Estimate requires sufficient criteria to prepare a Planning Estimate ranging from a description of the functional requirements to a brief description of the completed projects intent; the estimate is an order of magnitude estimate, estimated on a per square foot, linear foot, kilowatts, etc., basis; with a degree of accuracy of plus or minus 40 percent[5]. A Title II Design Estimate requires Title II drawings and specifications, which are final drawings and planning details, functional/operational requirements and tentative construction schedules; typically reflect a refinement of a Title I Estimate; with a range of accuracy of plus 15 percent to minus 5 percent. The accuracy of these two estimates is directly related to the amount of information available to the estimator. The Planning/Feasibility Study Estimate requires only rudimentary information whereas the Title II Design Estimate requires detailed drawing, construction information, scheduling details and so on.

The DOE's requirements for contingencies are equally as broad. The DOE defines contingency as: "Covers cost that may result from incomplete design, unforeseen and unpredictable conditions, or uncertainties within the defined project scope. The amount of the contingency will depend on the status of design, procurement, and construction; and the complexity and uncertainties of the component parts of the project. Contingency is not to be used to avoid making an accurate assessment of expected cost." The DOE stresses that contingencies are an integral part of the estimate and a contingency analysis will be performed for all cost estimates and maintained in the estimate file. The DOE provides contingency estimate ranges which can be used for small projects, but for large projects a more detailed analysis is required.

Typically, contingency guidelines provide information relating to the inclusion and exclusions of estimated costs. For example:

Estimated cost included in a contingency

- Incomplete or complex design
- Unforeseen and unpredictable conditions
- Incomplete or complex scope development
- Uncertainties (risk)
- Evolving market conditions, price, and competition

Estimating cost excluded in a contingency

- Cost to date
- Increases in the scope from project data sheet
- Alternatives in scope or method of accomplishment
- Murphy's Law

Depending on the industry and the type of estimate being performed, the number of contingency inclusions and exclusions is will vary markedly. Additionally, various factors affecting the project or activity need to be considered when selecting a specific contingency as a percent of other costs. As such, typical contingency ranges are often used for various projects and activities to account for unforeseen, unpredictable, and uncertain conditions. Table-1 shows typical percentage ranges used for contingencies of various types.

Table 1

Project Type	Contingency Range
Construction Project	
Engineering	15 – 25
Improvements to Land and Standard Equipment	10 – 15
Buildings (new & additions), other structures, and utilities	15 – 20
Buildings (modifications)	15 – 25
Special Facilities (standard)	20 – 30
Special Facilities (experimental/special conditions)	Up to 50
Management and Operations	
Management	10 – 15
Operations Support	10 – 15
Security	10 – 15
Training	10 – 15
Research	15 – 25
Engineering	15 – 25
Maintenance	10 – 15
Material Stores	10 – 15
Quality Control	10 – 15
Inspections, Test, and Analysis	10 – 15
Operations	15 – 25
Planning and Methods	15 – 20
Health Physics	10 – 15

State-of-the-art design, required reliability, equipment complexity, constrains and restraints resulting from continuity of operations, security, contamination, environmental concerns, scheduling, waste disposal, and other project specific concerns and considerations will affect the selection within the above ranges.

As mentioned previously, the contingency range and accuracy are dependent on the type of estimate being used, which is in turn is dependent on the level of data available for the estimate. The estimate basis for evaluating the contingency are type of work, quality of the scope description, point in project life, estimating method used, and the purpose of the estimate. Additionally, the contingency allowances that could be zero should be assigned to each cost element and the magnitude of the allowance should be derived from consideration of the type and degree of uncertainty.

The level of accuracy and uncertainty will vary from project to project depending on the method used to estimate the cost. The cost estimation methods may include factoring from material or equipment quantities rule-of-thumb, cost per unit of area, volume, weight, etc[6]. Generally, the contingency analysis will involve a review of the entire estimate to determine the risk of cost overruns associated with each element being considered. The level of detail for this analysis will vary depending on the type of estimate being performed. More specifically, if you were estimating the cost of a shed, the level of detail for the contingent cost would be negligable; whereas, if you were estimating the cost of building a Convention Center, the contingency cost would require considerable detail. Typical ranges used in contingency analyses based on various types of estimates as shown in table 2.

Table 2

Estimate Type[7]	**Contingency Range (percentage)**
Construction Project Estimates	
Study (before CDR)	
Standard	20 – 30
Experimental/Special conditions	Up to 30
Conceptual (based on FDC and CDR	
Standard	15 – 25
Experimental/Special conditions	Up to 40
Preliminary Design	10 – 20
Definitive Design	5 - 15
Government Cost Estimate	0

Current Working Estimate	
Engineering	
Before Detailed Design	15 – 25
After Detailed Design	10
Equipment Procurement	
Before Bid	
Budget	15 – 25
Title I	10 – 20
Title II	5 – 15
After Award:	
Cost Plus Award Fee	15
Fixed-Price Contract	1 – 5
After Delivery to Site	0
Construction	
Prior to Award:	
Budget	15 – 25
Title I	10 – 20
Title II	5 – 15
After Award:	
Cost Plus Award Fee	15 – 17
Fixed-Price Contract	3 – 8
Environmental Restoration Project Estimates	
Preliminary assessment/site investigation	
Planning Estimate for all Assessment Activities	Up to 100
Preliminary Estimate for all Assessment Activities	30 – 70
Remedial Investigation/feasibility Study	
Detailed Estimate for all Assessment Activities	15 – 55
Planning Estimate for all Cleanup Phase Activities	20 – 100
Remediation/Cleanup Phase	
Pre-design:	
Preliminary Estimate for all Cleanup Phase Activities	Up to 50
Remedial Design and Action:	
Detailed Estimate for all Remedation/Cleanup Phase Activities	0 – 25
Management and Operations Estimates	
Magnitude Estimate	
Standard	20 – 30
Experimental/Special Conditions	Up to 50
Preliminary Estimate	
Standard	15 – 25
Experimental/Special Conditions	Up to 40
Performance Estimate	5 – 15

Analyzing the Contingency Risk

Analyzing and evaluating the project-overrun risk captured by the contingent cost can be a tricky matter. If the cost estimate is base on an Order-of-Magnitude estimation, the contingent cost may be an educated guess based on past experience, rule of thumb, or some wild ass guess (WAG). Typically, the estimator will make certain assumptions, based on the information available, to assess the level of overrun risk involved with a particular project. If the estimate is reasonable, the estimator will not be questioned in great detail at this level of estimation. Order-of-Magnitude estimates usually have contingent cost with high overrun risk because of the lack or limited detail available to the estimator.

As the project progress the accuracy and level of detail required for the cost estimate increases, the estimator will have to refine both the cost estimate and the estimation of contingent cost. As the estimate is refined, and more project detail becomes available, the level of overrun risk is decreased. Part of the refined estimate detail involves the development of a risk analysis for the project at an element level.

Contingency cost risk analysis is an evaluation of the probability for project cost overruns. This type of analysis is typically performed with the aid of what is called a Monty Carlo Analysis. The analysis of risk uncertainty requires the evaluation of all-possible combinations and alternative available. Using conventional analytical methodologies we could easily spend an eternity evaluating the various alternatives available for a single contingency estimation

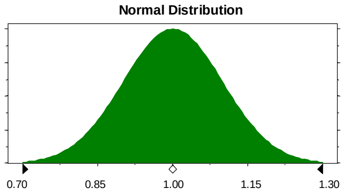
The Monty Carlo simulations allow us to evaluate and analyze risk based on the random selection of various alternative scenarios. This technique uses random numbers to create a sample based on a give distribution of the alternatives. Each random number represents an individual “what if” scenario for the estimate. This type of analysis is very useful and very deceiving, in its apparent simplicity. Software packages such as @Risk and CrystalBall provide risk analysis tools as add-ons to popular spreadsheet packages such as Lotus and Excel. These are just that tools. Much like a ShopSmith you may or may not recognize the name and even less likely you may or may not be familiar with the actual functionality of the tool. Once told the application of the tool you have a better idea of its use, but still not its specific nature.

The ShopSmith is a multi-purpose wood working tool that allows the user the functionality of several tools in one. Additionally, the ShopSmith comes in a variety of configuration based on price and need. For many individuals, even with the added information it is still unclear as to the usefulness of the ShopSmith. Likewise, risk analysis packages provide very powerful statistical tools that without proper training and experience can be every bit as dangerous as unfamiliar power tools.

One of the basic assumptions with any risk analysis package is that the use is very familiar with the data being analyzed. Knowing the behavioral characteristics of your data is vitally important to understanding the characteristics of the variables you wish to estimate. Knowing typical ranges for the data is not necessarily enough. You will also need to know how the data behaves and any characteristic changes that may be regionally or seasonally dependent. Does the basic data character change with the presence of other variables? Is any number in the range of values equally possible? How well do you really know the data your working with?

Most of us are familiar with the term Normal Distribution, which in a statistical content means normally distributed (what a surprise), when it is used in conjunction with statistical information. However, understanding how this and other distributions relate to our cost data is the real trick. As a refresher in basic statistics you may recall the characteristic bell curve of the normal distribution (as shown in figure 1), the fact that a standard normal has a mean (average) value of zero and a standard deviation of one (N(0,1)), and that a random sample is distributed normally if the sample is large enough. Unfortunate we rarely have the opportunity to deal with such complete and perfect data sets. Generally we deal with small data samples and make assumptions about the data's characteristics by estimating the average value and the data range. Occasionally, there is benchmark data available to provide the necessary statistical information for the risk analysis.

Figure 1



Using Risk Analysis packages we can generate surrogate data to assess the project-overrun risk for our contingency analysis. Risk Analysis packages typically rely on simple statistical information relating to the type of distribution, average value, standard deviation, data range, and possibly data increments. For example if we know that gas prices follow a normal distribution we can use this fact to generate additional data point for our risk analysis. The Risk Analysis package will allow us to enter an average value, the standard deviation, and the number of iterations or trials desired for the analysis. The greater the number of iterations used to generate the sample data set the closer the data sample will resemble the intended distribution.

Figure 2

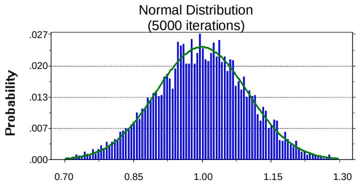
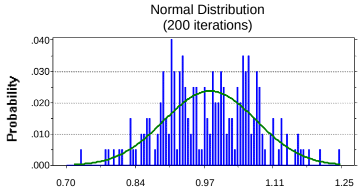
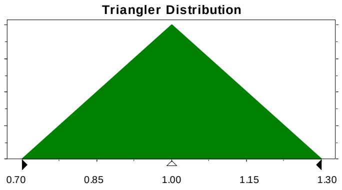

Normal Distribution
(5000 iterations)

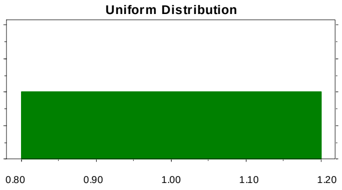
Figure 3

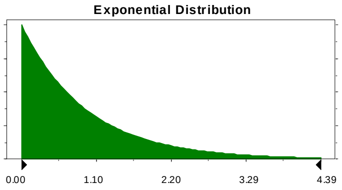

Normal Distribution
(200 iterations)

If you were to a generate a data sample using a normal distribution and instructing the Risk Analysis package to run 5000 iterations, the resulting data set would very closely resemble that of a typical normal distribution, as in figure 2. Whereas, if you were to use fewer iteration, say 200 trials, the resolution and definition of the data sample would be less representative of a typical normal distribution, as is apparent in figure 3. There are of course tradeoffs. The more iterations or trials used the closer you come to having a true representation of the data distribution, but it will take the program longer to run a single scenario. Whereas, if you use fewer iterations the analysis will take less time to run but the models resolution will also be less defined.

As would be expected, not all variables follow a Normal Distribution pattern. Some variables follow other familiar distributions patterns such as the Triangular, Uniform, or Exponential distributions (as shown in figure 4), or they may follow distributions similar to those in figure 5.

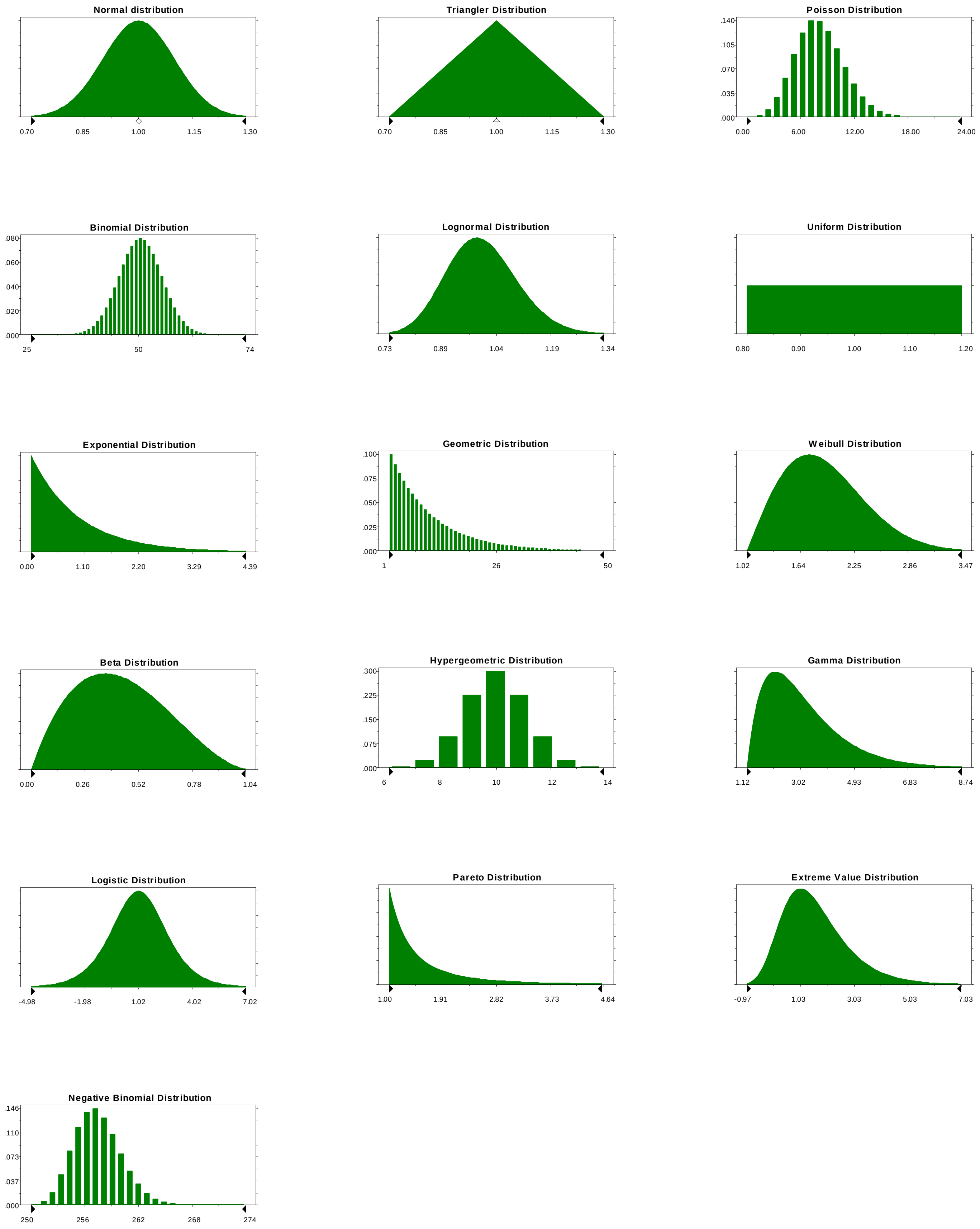

Triangler Distribution


Uniform Distribution


Exponential Distribution

To complicate maters, the distribution you use to analyze a particular variable may not reflect the variable’s character distribution but is appropriate for the current use of the variable. For instance, if the construction cost of a shed is expected to be between $50,000 and $80,000 and it is equally likely that the actual cost could be any value in the give range, than the probability distribution used for the analysis should be that of a Uniform Distribution. But the industry may state the cost of the shed follows a Triangular Distribution with a low end cost of $50,000, a high end cost $80,000, and a likelihood cost of $70,000 (likelihood is the expected or typical cost).

Figure 5


Normal distribution
0.70
0.85
1.00
1.15
1.30
Triangler Distribution
0.70
0.85
1.00
1.15
1.30
Poisson Distribution
.140
.105
.070
.035
.000
0.00
6.00
12.00
18.00
24.00
Binomial Distribution
.080
.060
.040
.020
.000
25
50
74
Lognormal Distribution
0.73
0.89
1.04
1.19
1.34
Uniform Distribution
0.80
0.90
1.00
1.10
1.20
Exponential Distribution
0.00
1.10
2.20
3.29
4.39
Geometric Distribution
.100
.075
.050
.025
.000
1
26
50
Weibull Distribution
1.02
1.64
2.25
2.86
3.47
Beta Distribution
0.00
0.26
0.52
0.78
1.04
Hypergeometric Distribution
.300
.225
.150
.075
.000
6
8
10
12
14
Gamma Distribution
1.12
3.02
4.93
6.83
8.74
Logistic Distribution
-4.98
-1.98
1.02
4.02
7.02
Pareto Distribution
1.00
1.91
2.82
3.73
4.64
Extreme Value Distribution
-0.97
1.03
3.03
5.03
7.03
Negative Binomial Distribution
.146
.110
.073
.037
.000
250
256
262
268
274

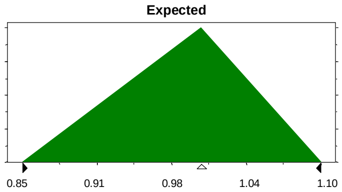
Understanding how to apply probabilistic distribution to our contingency analysis is a major step. There should not be a lot of guesswork involved at this point, however. It is important to select a distribution appropriate that reflects the cost behavior of the variables used in the analysis. This is where our knowledge of the data we are working with come in. Table 3, is an example of a variable list used in a contingency analysis for an actual project. For this particular project the estimator assumed a Triangular Distribution for every variable. This unfortunately is not an uncommon practice since Triangular Distributions are easy to explain and model.

Table 3

			Inputs		
Variables:		Low	Expected	High	MEAN
1	Craft Labor Variance	0.85	1.00	1.10	0.982276
2	Module Material Variance	0.90	1.00	1.20	1.033626
3	Module Scope Variance	0.95	1.00	1.50	1.151636
4	Module Mock-up	0.90	1.00	1.25	1.050164
5	Testing Craft labor	0.95	1.00	1.10	1.016669
6	Testing Engineering Labor	0.95	1.00	1.25	1.067428
7	Glovebag / Containment Waste Handling	0.85	1.00	1.20	1.015956
8	GB Labor (General)	0.95	1.00	1.15	1.032727
9	GB Material Cost	0.90	1.00	1.20	1.033611
10	GB Correct Wiring	0.95	1.00	1.10	1.016864
11	GB Scope of Work	0.85	1.00	1.50	1.113956
12	Perform Mock-up	0.90	1.00	1.20	1.033531
13	Leak Test	0.85	1.00	1.15	0.999062
14	Labor Variable	0.95	1.00	1.10	1.017465
15	Material Variable	0.95	1.00	1.05	0.999851
16	Scope Variable	0.95	1.00	1.15	1.032275
17	Glovebag / Containment Waste Handling	0.80	1.00	1.20	0.998854
18	Labor (General)	0.95	1.00	1.15	1.032487
19	Material Cost	0.90	1.00	1.20	1.031719
20	Scope of Work	0.80	1.00	1.50	1.100354
21	Leak Test Window	0.90	1.00	1.15	1.016309
22	Leak Test Piping	0.90	1.00	1.20	1.033885

The variable statistics required to generate a Triangular Distribution are a low range value, a high range value, and an average value. The values used are typically in terms of percentages reflecting typical cost estimate ranges (e.g. 85% to 110% with an expected value or average of 100%). The mean value is a result of the data sample generated from several iterations of the model. For each variable, the data from each iteration or trial is stored and an overall mean value (average) for each variable is determined. As an example, the “Craft Labor Variance”, the first listed variable in Table 3, has a distribution range of 85% to 110% with an expected value of 100% and is represented by the Triangular Distribution shown in figure 6. After 1000 iteration, the mean value is estimated to be 0.982276.

Figure 6



Once we have we have determined the appropriate distributions to be used for our analysis variables, we need to determine the resulting expected values follow our assumption regarding our cost data. Without knowing how each of our variables should perform, we can never know whether our final contingency estimates are realistic. Our knowledge of the data should be acute enough to evaluate the variable estimate through each step of the analysis. Our knowledge of the interaction between variable is very important at this point in the analysis.

After closely evaluating the resulting mean value of each of our variables we can proceed with the next step in the contingency analysis. The estimated mean values are applied to the appropriate estimated cost value associated with each variable. The mean value is used to determine how much of the estimated cost will need to be applied toward the contingency amount. Table-4 is an example of a contingency analysis employing this technique.

Table 4

Assumptions:		Estimate $ (000's)	Variables 1	2	3	4	5	Forecast	Sub Totals Est.	Fcst.	Contingency	% Increase
1.	Module E Rooms 125A & B	14.356	1	2	3	4		17.62798508				
2.	Module F Room 126	14.460	1	2	3	4		17.75568851				
3.	Module E Testing	89.809	5	6				97.4625974				
4.	Module E NDA Equipment	17.380	1	2	3			20.322	136.005	153.168	17.163	16.9%
5.	Glovebox E-20	25.494	8	9	11	13		30.28595366				
6.	Glovebox E-25	0.243	8	9				0.259387406				
7.	Glovebox E-60	9.453	7	8	9	11	13	11.40900654				
8.	Glovebox E-65	4.467	8	9	11			5.311615783				
9.	Glovebox E-70	5.809	8	9	11	12	13	7.132279081				
10.	Glovebox E-105/E110	62.288	7	8	9	10	12	70.99184977				
11.	Glovebox E-95	0.481	8	9				0.513437622				
12.	Glovebox E-125	0.785	8	9				0.838				
13.	Alternate Entry Glovebag	8.727	8	9	12			9.628	117.747	136.369	18.622	10.3%
14.	Construction Support	276.789	14	15	16			290.6693586				
15.	Construction Fees	54.273	14	15	16			56.995	331.062	347.664	16.602	5.0%
16.	Chainveyor Exhaust Mod. E East	42.961	17	18	19	20	21	55.34617213				
17.	Chainveyor Exhaust Mod. E West	51.709	17	18	19	20	22	66.616	94.670	121.962	27.292	28.8%
Totals		679.484						759.164	679.484	759.164	79.680	11.7%

Total Estimate With Contingency **$759,164**

The variable numbers in Table-4 correspond to the variable listed in Table-3. The forecast amount is determined by multiplying the estimated mean values of specific variables time the estimated cost of a particular line item. For example, in the first line of Table-4, the estimated value for "Module E Rooms 125A & B" is $14,136. This value is multiplied by the mean values for variables 1, 2, 3, and 4 ("Craft Labor Variance", "Module Material Variance", "Module Scope Variance", and "Module Mock-up") which are 0.982276, 1.033626, 1.151636, and 1.050164 respectively, resulting in an estimated forecast value of $17,628. Subtracting the original estimate cost of $14,136 from the forecasted value of $17,628, we have an estimated contingency value of $3,406. The estimated contingency amount is about 24 percent above the original estimated cost, which is also the product of the estimated means

$$(0.982276*1.033626*1.151636*1.050164=1.2373)$$

Formulations of this nature are common methods for the estimation of contingencies, but do not describe the only methodologies available. Econometric techniques also provide a wide variety of estimation methods for determining contingent cost, but also provide far to much subject matter to be covered in this paper justly.

Conclusion

Like the Cost Estimating, Contingency Analysis is an art. Evaluating cost to cover events that may or may not occur is seems crazy, but to be caught off guard because we didn't account for the possibility of cost overruns is even crazier. Like most risk analysis applications, the analysis of contingent costs parallels that of a good crossword puzzle with the added flavor of a game of chance. We think we know the outcome but we're not positive.

Contingency analysis requires time and patients. A though knowledge of the data being used is vital to the development of a usable contingency estimate. If we do not take the time to understand the underlying characteristics of the data we are using we will be unable to justify the assumptions we use and equally unable defend our analyses if they were to go to court. The biggest trick is finding good historical information to backup our assumptions. Unfortunately, the best data is our own data. So much of the data available to the general public or even government data is so plagued with holes, outliers, and junk that it is nearly worthless. If you find a good data source, hide it, shelter it, and protect it from corruption at all costs.

Lastly, build on you statistical background. Don’t just pass over unfamiliar terminology, instead make the struggle to understand the statistical basis associated with the risk analysis process. Understand the differences between the various probability distributions, how expected values are determined and how the expected value relates to a population mean. You don’t have to be a statistical guru, but you also don’t have to be statistically challenged.

Bibliography

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