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A Life Cycle Cost Model for Innovative Remediation Technologies

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THESIS

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ABSTRACT

LCC analysis is a powerful tool for investigating the costs of competing systems. This thesis investigates the cost scaling methods to improve the traditional LCC modeling techniques. The motivation for this research is finding a good estimate for the remediation technologies when the contaminant volume is not exactly known. This specific case lead researcher to investigating the methods of cost scaling and effects of inflation in the cost estimation. As a result of study a generic LCC model is developed. Methods for considering inflation and scaling are recommended and embodied into the model. The developed model is applied the specific case and used to analyze the cost of alternative remediation technologies.

Results of the research suggests that scaling can be accomplished with better accuracy if there is data and if the scaling can be performed at the level of cost elements in the cost breakdown structure. Inflation effects can be handle by ignoring or estimating the future inflation rates from the past rates. This study suggests that inflation rate should be investigated, before using general cost indices, for special elements which effects the cost of the system.

A LIFE CYCLE COST MODELING FOR
INNOVATIVE REMEDIATION TECHNOLOGIES

1. Introduction

1.1. Background

The Department of Energy (DOE) has been faced with an mountain of remediation projects. This dilemma reflects both the number and costs of the projects. The most critical of these projects are have been placed in the National Priority List (NPL), more popularly known as the Superfund. The National Research Council states:

"Superfund has become a massive program. The number of sites requiring cleanup turned out to be far greater than originally anticipated. In 1977, a year before Love Canal and three years before CERCLA, EPA had reported on hazardous contamination at only 421 sites. EPA now expects the NPL to reach 2,000 sites, although other sources have estimated that the eventual total could reach 10,000." [National Research Council,1994:2]

The DOE faces decisions in which a wide range of risk are involved. The sources of risk in these projects are widespread, ranging from those associated with the use of innovative technologies to those concerning unknown amounts and types of contamination as the remediation sites. These risks drastically affect the cost of remediation projects. The projects which have been completed thus far show wide discrepancies between their estimated cost of these projects and the actual cost after the remediation projects are implemented.

" Site remediation is also proving to be far more expensive than originally anticipated. The original Superfund of $1.6 Billion was designated to clean up 400 NPL sites at average cost of $3.6 million per site; but by 1990, EPA was projecting a total cost of $27 Billion at an average $26 million per site". [National Research Council,1994:2]

The potential public health and environmental risks motivate the DOE and the EPA to conduct massive remediation programs. To accomplish this critical national task the agencies involved require more efficient technologies and must reduce the risk associated with the use of these new technologies. Henriksen and Booth state:

> ...Over the next few decades , these sites will have to be identified, characterized, remediated and then monitored. There is an urgent need for innovative technologies to assist in this effort -technologies that can do the job better, faster, and at less cost, while simultaneously posing minimal additional risk to human health and the environment.
> [Henriksen and Booth,1994:7]

As stated above, new technologies will have their own risks in terms of cost, human health and environmental impact.

The cost of innovative technologies can be estimated through the use of life cycle cost (LCC) models. While there are a number of on-going efforts developing life cycle cost models, the wide adoption of a specific model for innovative remediation technologies has not occurred. This lack of a single model is due, in part, to the varying requirements and characteristics of specific technologies and sites.

1.2. Problem Statement

The DOE invests in a vast array of multi-million dollar-remediation projects and technologies. To develop and select the most cost effective approaches to these remediations, the uncertainties associated with innovative technologies and site characteristics must be assessed and utilized in the calculation of a net present value (NPV) profile of the cost of remediation. Uncertainties inherent in innovative technologies create risks in the decision that the DOE has to make. To identify and offer opportunities to decrease the level of risk the DOE must take, an LCC model which allows risk assessment is a desirable tool.

Economies of scale are another issue in cost estimating. Often, the exact scale of the project, system or plant to be constructed cannot be determined because of the uncertainties that affect the total system. Estimating the cost of a system for different capacities in advance is of crucial importance since increasing the capacity of an already working system can be much more expensive, dangerous, and time consuming than making the correct decision of initial capacity.

1.3. Objective and Scope of the problem

The objective of this research is to develop a generic, LCC model for innovative remediation technologies and to test the model on innovative technologies that are applicable to a specific remediation site as a proof of concept. The major cost estimating models developed thus far are examined and the superior features found in existing models are integrated into the model developed in this studying. In the proposed model, net present value calculations are combined with risk assessment techniques.

For many remediation projects the quantity of hazardous material is unknown; therefore, a model that can handle scaleability can increase the decision maker's insight into cost considerations. A second objective is to develop an LCC model with a scaleability feature.

Even though risk is created by the uncertainties which are inherit in the technologies, risk uncertainty and uncertainty are different. In this research, risk is assumed to be the probability of an undesired outcome occurs and refers to monetary risk associated with the selection from among alternative technologies.

The Visual Basic (VB) language provides a means to use an Excel spreadsheet for more flexible and specific calculations. More complicated and user specific functions, not provided by

Excel directly, can be developed and easily used. In addition, a user interface for the model, which allows user friendly interaction, is developed via VB macro code.

To allow further analysis of risk and cost effects, Crystal Ball is incorporated in the model. This program allows Monte Carlo simulation with an Excel spreadsheet. It also works well with VB to provide user friendly interfaces with the data used.

The generic LCC model developed is used for cost estimation of remediation technologies which are among the alternatives of a remediation project at a Paducah Kentucky site. The contamination was generated at the Paducah Gaseous Diffusion Plant, which is owned by the Department of Energy. The key contaminant is trichloroethylene (TCE) which has been used as cleaning solvent [Kerschus,1997:1-1,1-2)]. The alternative technologies- Dynamic Underground Stripping (DUS), Two Phase Extraction , In Situ Chemical Oxidation (ISCO) and Six Phase Soil Heating- form the following trains[Kerschus,1997:3.6].

TRAIN	DESCRIPTION
1	DUS & 2 Phase
2	2 Phase & ISCO
3	6 Phase & ISCO

Table 1-1 Description of Trains

The term "Train" is used to refer to the technology or technology group which is/are used at the remediation site in Paducah. A train can include up to three different technologies as well as the one technology. In this study, trains of two technologies are used.

The cost estimations of the above trains are done as an application of the developed LCC Model. The analysis result of the application are presented in Chapter Four. The conclusion of the research, consists of the result of the application and the points reached to handle the scaleablitiy of the project in cost estimation.

2. Literature Review

Making a decision among the alternative remediation technologies requires accurate estimation of each alternative's cost. Remediation costs are often influenced by the specific site characteristics. First, the nature of the cost estimating methods and life cycle cost estimation is reviewed and the fundamentals of life cycle cost models are outlined. The stochastic nature of cost estimating and risk analysis methods to deal with it are then studied. Methods to accurately integrate scaling, a main objective of the research, in the cost model are reviewed. Finally, the effects of inflation on cost estimation is reviewed.

2.1. Life Cycle Costing

The purchase price of a system is only one part of the total cost of the system. While a system's acquisition cost is a key driver, a "white elephant" which is obtained cheaply, but requires extensive costs to maintain, is not desirable. The real cost of a system is the sum of all cash flow streams during the system's active life, from acquisition through operation to decommissioning. For high cost systems the analysis of design, development, manufacturing, operation, maintenance, phase out and disposal costs for each alternative system is of crucial importance to selecting the most cost effective system. Life cycle cost (LCC) refers to all costs associated with the product or system as applied to the defined life cycle[Fabrycky,1991:125]. The total cost of a system can be estimated by employing comprehensive LCC models. Net Present Cost (NPC) calculations, considering the time value of money, are the basis of LCC models.

In a stochastic LCC models, some of the cost elements are not known exactly; the expected value of NPC must be calculated. This one number is useful in the evaluation of alternatives; however, it is insufficient for good analysis, since it does not give information about the variations in cost. Risk analysis should be employed according to the cost distribution with a confidence interval on the estimate.

2.1.1. The Time Value of Money

Dealing with systems that have different life times, leads an analyst to compare the alternatives on an equivalent basis [Blanchard, 1978:50]. The time value of money is the determining factor for the equivalent basis.

A dollar in hand now is worth more than a dollar received in the future , because having the dollar now gives the decision maker the opportunity of investing [Fabrycky,1991:30]. Since this investment yields a return, the investor has more money in the future than the amount originally received. Therefore, a future dollar is discounted to find its present value.

Discounting the future value of money employs the interest which, simply, is the rent paid for the use of money of the gain received from an investment [Blanchard, 1978:51]. Interest is represented by an interest rate, a number that shows the ration of the interest that is charged during a period [Fleischer, 1984: 14]. Discounting allows for comparison of the alternatives with different cash streams by calculating the present value which is the value if all the payments of alternatives occurred in the present. The present value of a future payment can then be calculated given by the following equation [Fabrycky, 1991:42].

$$\text{Present Value} = \frac{1}{(1+i)^n} \cdot \text{Future Payment}$$

In the above equation *i* represents the interest rate per period (year) while n is the number of periods(years) to the payment.

2.1.2. Cost Estimating Methods

A cost estimate is an opinion based on an analysis and judgment of the cost of a product, system, or structure[Fabrycky,1991:144]. Fabrycky suggests there are three kinds of cost estimating methods under two categories, which are illustrated in Figure 1. Estimating by engineering procedure is an in-depth estimation of the system segments. For this method, a detailed outline of the system should be available. It is accepted as the most accurate cost estimation method. Parametric estimating methods and estimating by analogy are top down methods. Estimating by analogy concerns estimating the system cost by examining similar system. It can be employed when undertaking all new activity or technology in which no reliable specific data is available. Parametric estimating methods use statistical techniques. The objective is to find the relation between cost and the factor(s) upon which the cost depends[Fabrycky,1991:144-147].

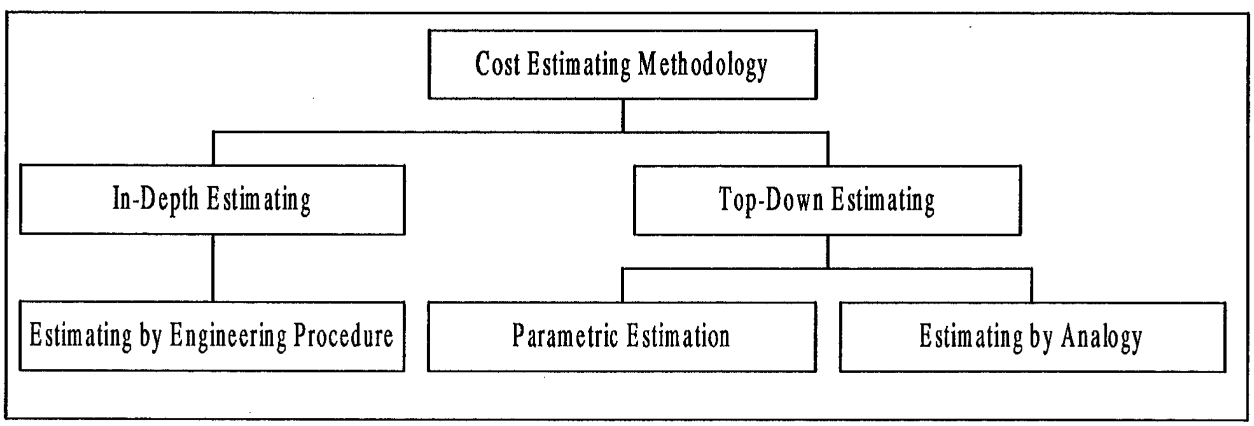


Figure 2-1 Cost Estimating Metodology

Parametric estimating methods allow the estimation of future technology costs according to the system's work breakdown structures. Some advantages of parametric estimating methods are listed as follows:

- The cost estimates are based on general system characteristics, no detailed information is necessary;
- The model is very fast and easy to use;
- The model is resistant to user bias;
- Confidence intervals can be placed on forecasts since parametric statistics are used in generating the forecasts [Habas,1992:14].

The fourth advantage has crucial importance since, in this thesis, not only NPCs are evaluated but also risks are assessed.

On the other hand, parametric estimation methods have disadvantages. While a parametric estimate does not require detailed information, this advantage also can be a disadvantage because of the inherent lower accuracy when compared to engineering procedures. Effects of being dependent on historical data and limited in-depth visibility are stated by Stewart [Stewart,1991,63]. Historical data may be misleading due to rapidly changing conditions and technologies. To prevent erroneous estimation Stewart points out that parametric estimation is reliable in the range of historical data. Seldon echoes this point when he warns that the Cost Estimating Relations (CER) should be used with caution outside of the range over which the were developed [Seldon,1979:31].

Parametric estimates are most efficient when the work is subdivided into the smallest possible elements [Stewart,1991:63]. This can be done by utilizing the work's Cost Breakdown Structure (CBS). This is a kind of classification of the costs which helps in including every segment of the total cost. The CBS must be expanded to include a detail description of each cost category, along with the symbology and quantitative relationships used to derive the costs [Fabrcyky,1991:28-30].

There are other ways to classify cost; first or investment cost, operation and maintenance cost, fixed and variable cost, increment or marginal cost, direct and indirect cost, total and unit cost, recurring and nonrecurring cost and sunk or past cost. As stated above, the CBS determines the classification of the cost elements.

Cost categorization can be made in many ways. Henriksen and Booth [1994:195] define two categories; capital and operation. Capital includes all cost until operation begins. These are generally nonrecurrent costs like costs of building facilities, installation, purchasing new equipment. The second category includes operation costs like direct labor, maintenance, transportation, administration cost.

Humphreys and Wellman give the definitions of cost categories in more detail. Direct capital cost is the cost of all material and labor involved in the fabrication, installation, and erection of facilities while indirect capital cost is associated with construction but not directly related to fabrication, installation and erection of the facilities[Humphrey,1996:255-256]. They also state that fixed capital cost includes all the costs incidental to getting the property in place and in operating condition, including legal costs, purchased patents, and paid-up licenses. Maintenance cost is defined in the same reference as the cost both for labor and materials, required to keep equipment or other installations in suitably operable condition while the manufacturing cost, (in our case operation cost), is the total of variable and fixed or direct and indirect costs chargeable to the production of a given product and usually expressed in dollars per unit of production.

The literature supports the conclusion that the cost element classification that most accurately represents the cost behavior should be used in the model.

2.1.3. Work Breakdown Structure

Stewart defines the work breakdown structure (WBS) as "the estimate skeleton" [Stewart,1991:35]. Stewart also stated that the development of the WBS is the first step in developing a cost estimate of any kind of work output. The importance of the WBS and its characteristics have also been stressed by Blanchard [1978:33], and Fabrycky and Blanchard[1991:28]. Stewart [1991:35] discussed the purposes of developing a WBS. The main objective is to assure that all key cost elements, according to level of estimation, are covered. The WBS provides a framework for a systematic approach to data collection while preventing the overlaps.

In the remediation field several studies that have been done to estimate remediation projects costs work. In these efforts, cost models are built from the WBSs developed by experts. White et al used a WBS which was developed according to Feasibility Study Report (FSR). It is provided in Figure 2.2 [White et al, 1995:49].

One of the most widely used remediation estimating tools in the US Air Force is RACER (Remedial Action Cost Engineering and Requirements). Different categorizations of cost elements are used in RACER. Even though RACER has a broad WBS, it does not include Research and Development cost. RACER's WBS is given in Figure 2.3.

White et al WBS

I. Research and Development

II. Construction/Capital Equipment

  A. Facilities
  B. Capital equipment

III. Operations and Maintenance

  A. Operations
  B. Maintenance

III. System Phase-out and Disposal

  A. Waste storage
  B. Waste transport
  C. Equipment Salvage
  D. Facilities Destruction
  E. Site restoration
  F. Long term monitoring

Figure 2-2 WBS White et al

Racer WBS

I. Site Preparation

II. Site Improvements

III. Site Civil / Mechanical Utilities

IV. Site Electrical Utilities

V. Environmental

VI. Contractor Overhead and Profit

Figure 2-3 WBS RACER

MSE, Technology Application, Inc. has developed a similar WBS driven cost model. MSE's model has Capital cost and Operating cost. Like RACER, it does not include Research and Development cost. MSE's model also does not have a separate category for disposal and phase-out cost.

The Federal Remediation Technologies Roundtable (FRTR) has developed a guide to documenting cost and performance for remediation projects to standardize the procedure and the parameters which are used in cost estimation. They presented a WBS based on the Interagency Cost Engineering Group works. FRTR' s WBS has three basic categories, Before treatment cost elements, Treatment, and After treatment cost elements [FRTR,1995: 40].

2.1.4. Cost Elements

Work Breakdown Structures (WBS) show the activities which creates the costs. By following the WBS, one can include all the cost elements, assuming completeness of the WBS. At this step, there is a question that should be asked. How should a cost element be represented in the model? This can be answered by looking at the actual occurrence of the cost element. Habash suggests the following ways to represent cost elements in the model[Habash, 1992:25-28]. These are Trapezoid cost elements (TCE), Percentage cost elements(PCE) and Probabilistic cost elements.

A payment profile of a cost element can be approximated by a trapezoid [Habas, 1992:25]. The left triangle of trapezoid represents the phase-in period, when payments increase as the project grows in size. The rectangle in the center represents the constant cost period during the operating years. The right triangle represents the phase-out period with decreasing payments over the phase out. In the cost model they developed, White et al used a trapezoid cost element to model research and development cost.

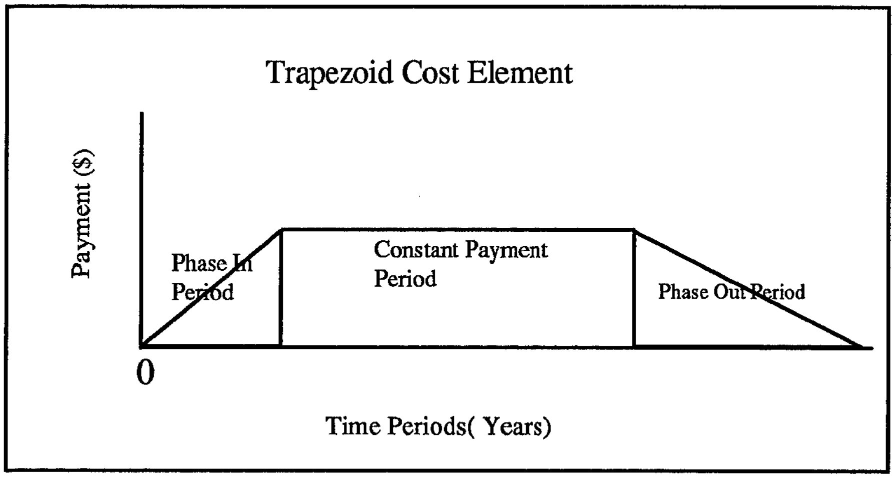


Figure 2-4 Trapezoid Cost Element

In the percentage cost element method, the payments over the life of the system are represented by the designated percentages of the cost. For example, payments for an equipment cost element can be 25% of total purchase price in the first year, 50% in third year and the 25 % in the forth year of the project. Figure 2.4 shows the example of payments of percentage cost element.

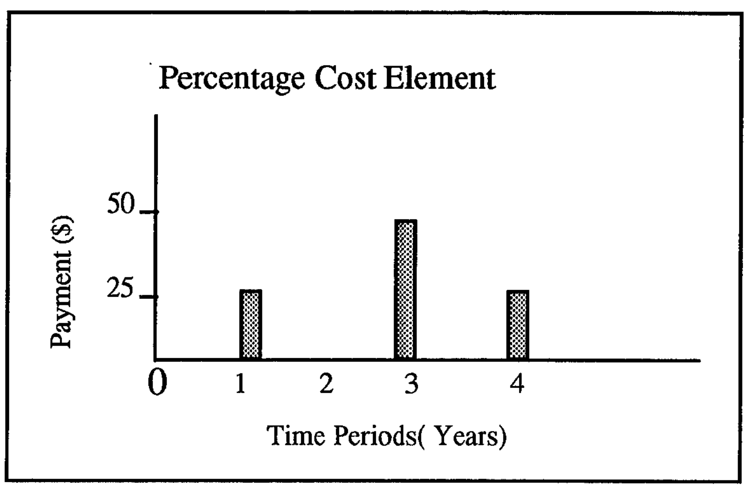


Figure 2-5 Percentage Cost Element

When modeling the time phasing of the cost elements, recurring cost element (RCE), the suitable one for a wide variety of payment types, is used most often. The Recurring Cost element can be used when modeling the payments that repeated in specific periods like operating and maintenance cost, or annual labor cost. Figure 2.5 illustrates the character of recurring cost.

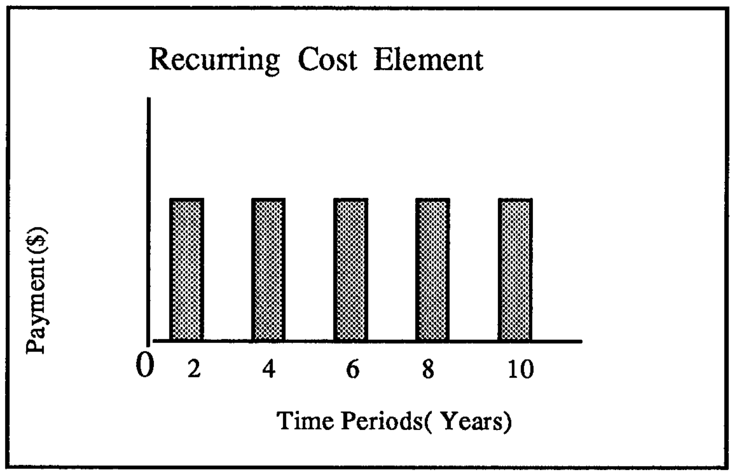


Figure 2-6 Recurring Cost Element

Sometimes the exact cost of an equipment or activity cannot be calculated. Hershauer and Nabieslsky introduced a method for estimating the duration of a project which can be applied to estimating a cost element [Hershauer and Nabieslsky,1972;9]. In the method, they suggest that the analysis should be depend upon the degree of knowledge. Depending on the level of knowledge that exists, the analyst can estimate cost elements. According to the information at hand for the remediation technologies only the range and the parameters for cost have been estimated. Beta and Triangular distributions are the most commonly used distributions in this situation. The Beta distribution can take almost any shape with its three parameters. On the other hand, the triangular distribution is easy to implement with its lower, higher and the most probable values when dependable historical data is not available and expert opinion must be relied on.

2.1.5. LCC Models

LCC models should meet certain requirements in terms of efficient modeling, flexibility, and user friendliness. These requirements are summarized by Fabrycky and Blanchard[134].

- Model should cover all possible cost factors and be comprehensive , and the results should be repeatable.
- Model should be relatively sensitive to the important cost elements' parameters and should well represent the dynamics of the system.
- Model should be flexible so that an analyst can evaluate the overall system as well as each cost relationships of system components.
- Model should be easy to implement in terms of time and effort required.
- Model should be easily expandable when additional capabilities needed.

Each of the entries listed above should be seen as the foundations requirements of an LCC model. On this foundation some general and specific features should be built. These features can change according to the area in which the model will be used. Mark Twomey, in a review of a subset of LCC models used in the USAF, states some criteria in terms of the features that should be in a LCC model. Twomey's research indicates that the following features are desirable for an LCC [1991:213]:

- LCC phase coverage: model should cover every phase of the system from R&D to disposal.
- Model should be formally validated.
- Model should cover operational availability, a measure which estimates the proportion of time that a system (weapon system) should be available for use.
- Budget estimates.
- Risk analysis.
- Inflation adjustments.
- Discounting.
- Sensitivity analysis capability.
- User friendliness.

The features presented above increase the power of the LCC model as an estimation tool. Coverage is concerned with every possible cost element being represented in the model relative to its effect. Completeness of the model in terms of the cost elements is perhaps the most important feature of the model. Since the LCC model is an analytical model like a wide array of other models, validation is an essential part of the modeling exercise.

Risk analysis becomes important especially when the uncertainty associated with the system cost elements is high. This feature allows the analyst to consider possible outcomes other than NPC during the evaluation of the alternative systems. It should be one of the inseparable parts of the LCC model for innovative technologies.

A user will want to use a generic model under different circumstances. For this reason, the model should be able to keep up with the real life changes in factors such as interest rates and inflation effect. This is particularly true for systems with long lifes. Inflation effects should be taken into consideration.

During the decision making process, the analyst should be able to answer key "What if?" questions. The model should provide tools to conduct sensitivity analysis, an item of crucial importance when investigating wider aspect of the alternatives and their effect on the decision.

Another key feature is the user friendliness of the model. Quick input, easy interface, effective control from overall model to individual cost elements, and short run time are the important issues in assuring the effective use of the model and ultimately, for better estimation.

In this research some of the cost estimating models are revisited and their most powerful features are embodied into one model. This research is primarily focused on RACER, the DNAPL Scaleable Life Cycle Costing Model, by MSE, and Life Cycle Cost Analysis for Radioactive

Waste Remediation Alternatives, by White et al. Each of these models have certain features which are superior to the other models. The model developed in this research attempts to incorporate the best features of each of the previous attempts at calculating LCC. Table 2.1 gives more insight about these models' features.

FEATURE	RACER	MSE	WHITE
Phase Coverage	No R&D	No R&D	Yes
Validated	Yes	No	Yes
Risk Analysis	No	No	Yes
Sensitivity Analysis	No	Yes	Yes
Flexible	Yes	Yes	Yes
User Friendliness	Yes	Yes	No
Expandable	Yes	Yes	No

Table 2-1 Comparison of Models

In light of the information above, the model that is developed incorporates the following key features.

- Comprehensive over all possible key cost elements.
- Sensitivity analysis tools
- Risk analysis tools
- Inflation Adjustment
- User interface in Visual Basic © to ease the control of the model components.

2.2. Cost Scaling

One of the important decisions in system or project analysis is defining the capacity of the facilities. To prevent the need for future capacity increases which may cause important cost escalation, the possible capacities should be considered in cost estimation model. Estimating the cost depending on capacity can be explained by Economics of Scale. Even though it is an important point in cost estimating, there is only limited literature about cost scaling. This literature focuses primarily on production cost scaling, which is reviewed below.

Cost engineering approach divides the product's cost into determining factors, which simply allows for calculating the total cost of a process Magrab provides a general equation for total cost of producing a product [1997:48]

$$C_p = N_p (M + L + R) + T_o + S + D$$

C_p: Total Cost for product volume of p.
N_p: Lifetime product volume(Total number of units)
M : Material cost/unit
L : Direct labor for manufacturing and assembly/unit
R : Production resource usage/unit
T_o: Tooling and capitalization cost (usually one-time costs)
S : System cost(Overhead or indirect costs)
D : Development costs

From the equation above, it can be seen that three factors, material cost per unit, direct labor from manufacturing a unit and production resource usage per unit, should be take into consideration when calculating the cost of specific volume of product. On the other hand, the rest of the factors seem independent of the volume of product. It is reasonable to assume independence when a production plant is already built and tooled or a range of production rates has been dedicated. The scaling of the cost is then a matter of the volume to be produced. The total cost is a linear function of these three factors, material, direct labor and production resource usage, which is translated by other factors.

The above equation is a reasonable approach for a defined capacity range in which the level of production volume changes. The general idea is applicable to remediation technologies when the volume range of the contamination is known. Unfortunately in some of remediation cases that the volume of the contaminant is the biggest source of uncertainty. Since time is another cost factor, building a facility at an estimated capacity also affects the operating and maintenance costs. In some cases, keeping the operating time short may help to keep the total cost low. Thus, the tooling and capitalization cost and system cost should be estimated depending on volume of production, that is the volume to be remediated.

2.2.1. Exponential Scaling

In fulfilling the research objectives of the study, estimating the cost of technology for different volumes of the contaminant more accurately, the second part of the above equation is studied in detail. This matter is explained under capital cost estimation by different authors.

Capital cost estimation is discussed by Humphrey and Wellman. They give a classification of capital cost estimates [Humphrey,1996:7]. They stressed Order-of-Magnitude (ratio) estimates and Study (Factored) estimates.

Order-of-magnitude estimates are easy to prepare but generally have the least accuracy. At best, this kind of estimate gives accuracy of -30% to +50% [Humphrey, 1996:8]. The formula for estimation is:

$$C_x = C_k \left(\frac{E_x}{E_k} \right)^n$$

Where,

C_x = Cost of plant and/or equipment item of size E_x

C_k = Known cost of plant and/or equipment item of size E_k

n = Cost capacity exponent.

The cost capacity exponent, n, represents the relation between capacity and cost of the system. To show the effects of n, and extend the concept to a DNAPL remediation where plant size Ex is replaced by spill volume, consider the following condition:

E_k= 250,000 Gallons and C_k = \$100,000

The following example graph shows the effect of different values of n by changing capacities of the system.

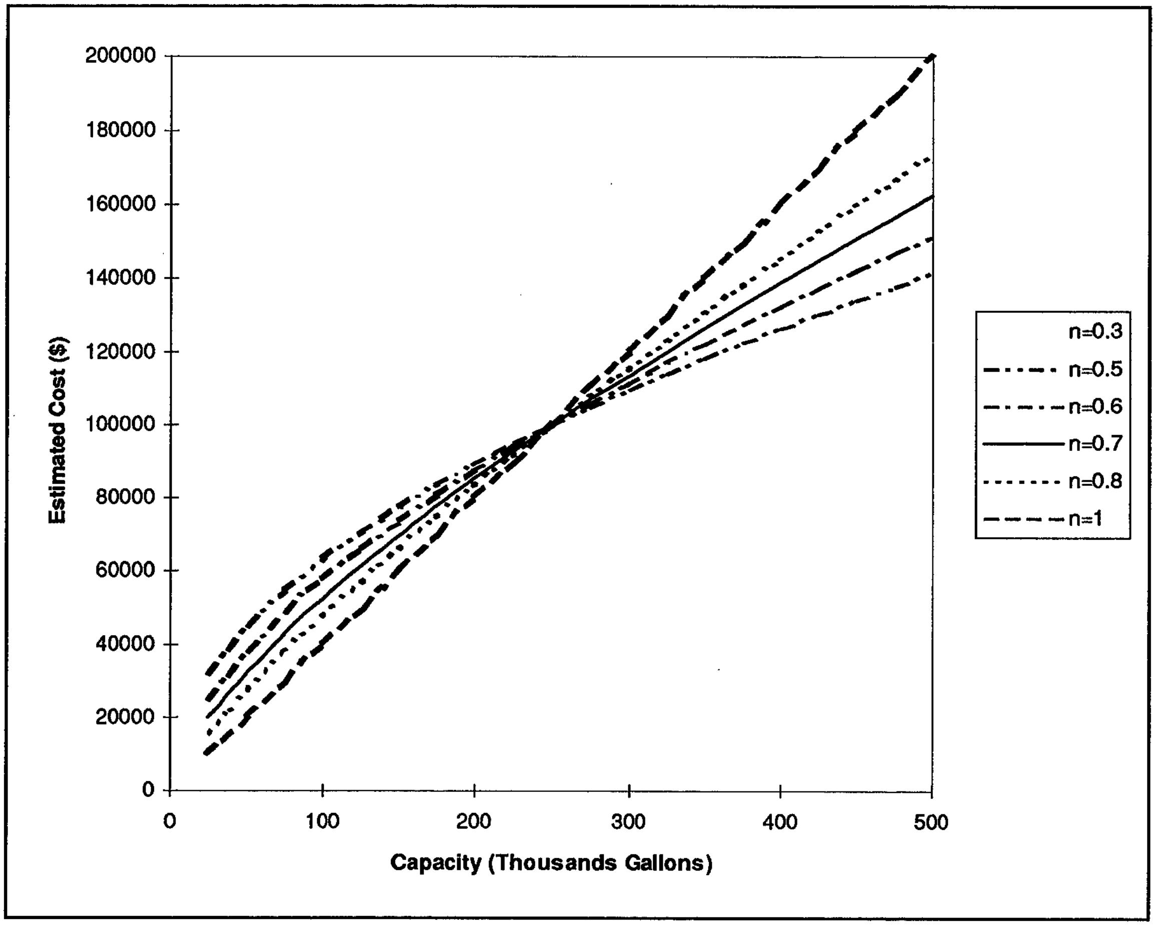


Figure 2-7 Scaling Exponent

Estimated cost is graphed against the capacity for the values of n from 0.3 to 1. The range of n values in actual applications is from 0.3 to 1 and for some special cases greater than 1 [Humphreys , 1996:9-11]. Even small changes in n can cause significant change in the estimated cost. Another point is the ratio between the capacities, base capacity and estimated capacity. As the ratio increases, the difference created by changing n values significantly increases.

Deciding the value of n is the main issue in the application of this formula. Historical data or price research (for equipment) should be used to define the value of the n which represents the relation between cost and capacity. It should not be forgotten that the use of n without historical data may cause considerable error in estimated cost.

For cases where data is not available, the specific case of order-of -magnitude, the six-tenth rule can be employed. In this case, the exponent (n) has an approximate value of 0.6-0.7 [Humphreys, 1996:9]. The main shortcoming of this approach is the value of the exponent is actually not constant [Humphreys, 1996:9]. It changes by changing equipment size. It is suggested by Humphrey and Wellman that this method shows maximum accuracy for ratio, E_x/E_k, 2:1 and should not be used for ratios greater than 5:1. To provide more insight about this suggestion, the same example is plotted for the ratios between 0 and 10 for n=0.61-0.70.

The graph in Figure 2-8 again shows the importance of the value of n. Using the sixth tens rule, (n=0.6-0.7) for the higher ratios even a small difference in the n value causes significant difference in estimated cost. From the calculations of graph the difference of estimated cost between n=0.6 and n=0.7 is around 15%, at ratio 5:1. In the application defining the value of n may not be more accurate then two decimal points, so this inevitable error may lead the cost estimate errors beyond the affordable limits. For higher ratios, as Humphrey suggests, the six tenth rule should not be used [Humphreys, 1996:9].

2.2.2. Scaling by Cost Estimation Relationships (CER)

Another way to consider cost scaling is to use Cost Estimating Relationships (CER) for plant or equipment. Basically CERs are mathematical models or graphs that estimate cost [Ostwald,1992:197]. Defined parameters help to predict the cost for changing input variables. Parametric cost estimating relationships relate various categories of cost-to-cost-generating or explanatory variables of one form or another [Fabrycky,1991:159]. The explanatory variables stressed by Fabrycky can be units produced, volume, or process time.

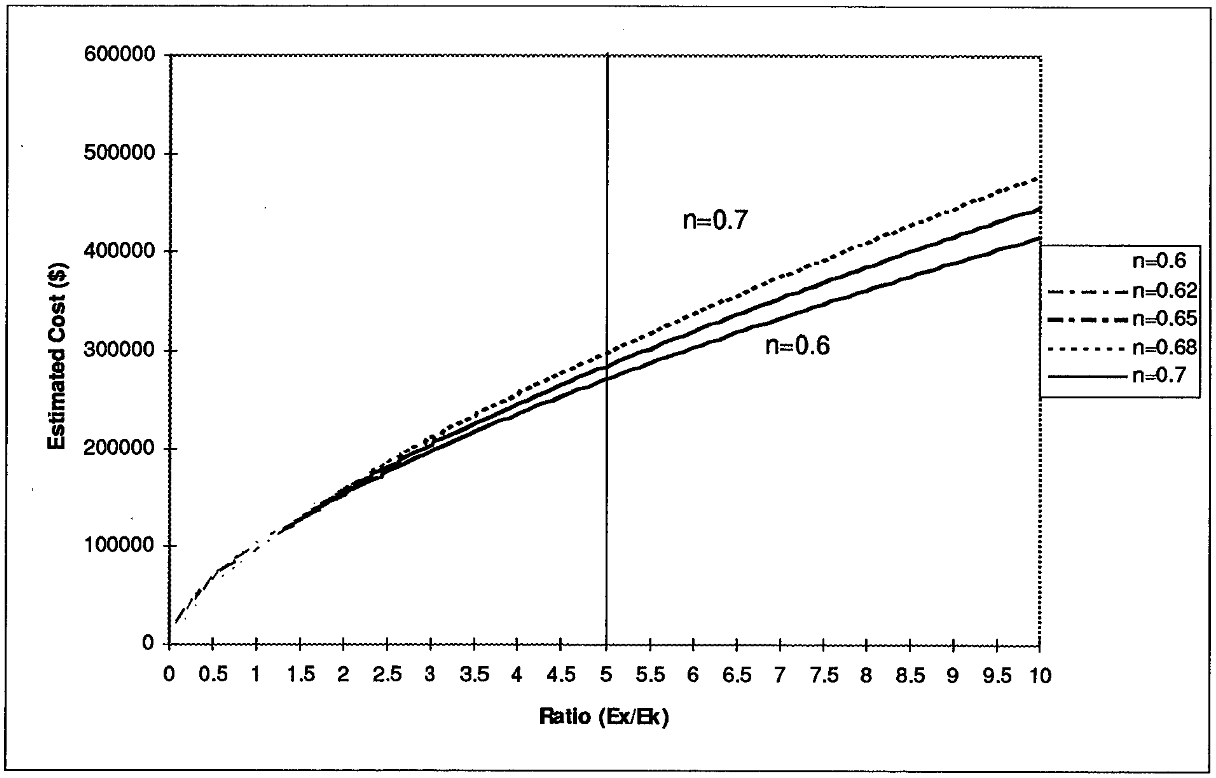


Figure 2-8 Six-Tenth Rule

The estimation function is generally in the form of a regression model. Regression models have one or more independent variables which are selected as the most important cost drivers by decision maker. The model structure can be in different forms such as quadratic, logarithmic or linear. Followings are the examples of the forms of cost estimating functions.

$$C = \beta_0 + \beta_1 . X \ldots\ldots\ldots\ldots\ldots\ldots (Linear)$$
$$C = \beta_0 + \beta_1 . X + \beta_2 . X^2 \ldots . (Quadratic)$$
$$C = \beta_0 \ln X \ldots\ldots\ldots\ldots\ldots\ldots\ldots (Logarithmic)$$

Besides its advantages, one should keep in mind that the regression models do not necessarily imply a cause-and-effect relation between independent variables and dependent variable [Neter, 1990:9]. The model represents statistical relation between dependent variable and independent variables. This relations may not be enough to fully explain the effects of each variable. Multi-collinearity between the independent variables alias the effects of each others. Therefore, when using regression model, the model should be analyzed in depth.

The cost of system, equation or a service can be estimated by using the relation between the desired capacity and the cost.

2.2.3. Exponential Vs. Best-fit Equation

Bielefeld and Rucklos have compared exponential scaling factor to a best-fit equation (Regression model) that they developed from the prices of the pumps of different flow rate and head [Bielefeld and Rucklos,1992:15]. They conclude that using the regression models allows better estimate for the cost. They present a method for using the scaling factors. In the method scaling is accomplished by calculating the ratio between predicted costs of the two capacities.

$$Cost_B = Cost_A x \frac{f(E_B)}{f(E_A)}$$

where

$f(E_B)$ = Predicted cost for capacity E_B.

$f(E_A)$ = Predicted cost for capacity E_A.

$Cost_A$ = Actual cost of capacity E_A

$Cost_B$ = Estimated cost of capacity E_B

This method, in principle, is same as using CERs. If cost engineer has a CER which is developed in advance it can be used to find the ratio of the estimated costs and multiplying the actual cost with this ration gives the final estimation.

2.3. Inflation

When dealing with cost estimation, one wants to consider every important variable so that the estimate is close to the actual cost. Inflation would be one of the important variables if the general price level have fluctuation and the analysis involves along time horizon.

2.3.1. Definition and Mathematical Representation

There are several definitions of inflation from different aspects in the literature. Even though there is no generally acceptable or satisfactory definition [Frisch, 1983:9], the following definition is commonly accepted "Inflation is a process of continuously rising prices, or equivalently, of continuously falling value of money" [Laidler and Parkin, 1975:741]

In addition to providing a definition of the inflation, Frisch gives three important comments [Frisch, 1983:9,10].

a. Not all the price increases can be named as inflation. The increase in the prices should be continuous and irreversible. Otherwise one cannot call the price increase as inflation.

b. To speak of inflation the general price level should increase. The increases in individual commodities' prices cannot be inflation.

c. Rate of inflation is necessarily a subjective criterion, which represents the sensitivity of the economic agents. Thus rates less than one percent should not be called as inflation.

Inflation, as defined above, is an increase in the prices of goods and services in a period. A good mathematical representation of inflation is given by Jones [Jones,1982:11]. In the equation below p(t) is the value of the dollar at time t, which is the weighted average of the prices at time t [Frisch, 1983,10]. Δt is the time period where f represents the inflation rate for time period Δt.

$$p(t+\Delta t) = p(t)x(1+f)$$

Even though the above equation of the inflation is simple, in actual applications, the following one is more commonly used [Park,1993:518].

$$p(t_2) = p(t_1)x(1+f)^n$$

In the second equation $p(t_1)$ is the price level at time t_1 and $p(t_2)$ is the price level at time t_2. "n" is the number of periods and f is inflation rate per period. In the application by assuming the inflation rate as constant, (which may lead to serious error), the price level at the time t_2 can be found.

Price indexes may be employed when using historical data for scaling a system cost, resulting in an equation represents the cost at a time in the past. To update the cost is then a matter of a calculation with the following formula[Humphrey,1996: 9].

$$C_A = C_B\left(\frac{I_A}{I_B}\right)$$

C_A = Cost of plant and/or equipment item at index value I_A
C_B = Known cost of plant and/or equipment item at index value I_B
I_A = Cost index belongs to the year that cost estimated.
I_B = Cost index when the data is collected.

2.3.2. Constant and Actual Dollars

Inflation calculations require understanding of two approaches to value of money: Actual Dollars Analysis and Constant Dollars Analysis. Actual dollars represent the dollars disbursed at any point in time while constants dollars represent the hypothetical purchasing power of future monetary amounts in terms of the purchasing power of dollars at some base year [Fabrycky ,1991:67]. The relation between two approaches can be shown as:

$$Constant\ Dollars = \frac{1}{(1+f)^n}.ActualDollars$$

f: inflation rate,

n: the number of years between base year and the year that money flow occurs.

System cost estimation can be done by representing the money flows either in actual dollars or constant dollars. Using constant dollars based on the present year would be more meaningful in terms of judging the purchasing power of the estimated value of the cost. On the other hand, estimating the actual costs for the year to come would be more helpful for planning the project. Each can be converted to the other by using the above formula

2.3.3. Inflation in Cost Estimation

The impact of the inflation in cost estimation should be taken into consideration from different aspects. During the estimation of costs, we should make some assumptions to reduce the complexity of the inflation calculation. Extra care should be taken while estimating the future inflation rate, stay in the affordable limits of estimation error. Particularly for future projects which have the long life, inflation becomes an important factor. Different authors suggest different ways to consider the inflation.

Humphreys and Wellman suggests using only current dollars because of the unpredictable nature of the inflation in the future. They defend that estimation of any accuracy cannot be accomplished. Thus, they conclude, estimates should be made in current dollars [Humphreys and Wellman, 1996:219]. While such an approach may be effective in an economy with low inflation rates, it may lead to serious errors in economies where inflation rates are high.

Humphreys and Wellman's suggestion aims to radically solve one of the biggest problems in the inflation, inherent in its nature, errors in forecasting the future inflation rates. A different approach to same problem is to use the tendency of increase in the rate of inflation. This means that estimating next year's inflation rate depending on the year before it, which gives a pretty good estimation [Moore,1983:174]. Taking advantage of the inertia in the rate of inflation has a drawback, since the calculated inflation rates based on the past tend to stay behind of the actual rate of the inflation since inflation rate is not constant.

The other issue is that the inflation rate in standard indexes, Consumer Price Index (CPI), Wholesales Price Index (WPI), may be misleading for some cost elements. The rate of inflation is a weighted average of the all individual price increases. Prices of some goods or services may increase more than the others. Stewart states that:

"Cost estimators must evaluate the effects of inflation on each specific work element of a process, product, project or service separately. The resource content and inflation of each element can vary within a work activity or work output as well as between the work output"[Stewart,1991:212].

A special study for accounting for inflation in DoD budgets developed a major system price index compared to GNP index [CBO, 1986,xi]. The following table shows the difference between two indexes. Major systems refer to defense systems like aircraft, missiles, and ships.

Relation Between Inflation Rates for Major Systems and GNP Inflation Rates.

Price Index	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**Average**
BEA Major System Index	12.2	10.9	12.6	11.1	6.7	4.2	2.1	8.5
GNP Fixed Weight Index	8.4	9.3	9.3	6.3	4.1	4.2	3.5	6.4
Major System/ GNP	1.46	1.18	1.36	1.77	1.64	1.00	0.60	1.32

From A Special Study, Budgeting for Defense Inflation,
prepared by Congressional Budget Office, January 1986

Table 2-2.

Rates of inflation for the two indexes are significantly different, supporting Stewart's idea. On the other hand, it cannot be stated that the Major System's inflation is always higher because of the special element costs and high tech equipment price. As a conclusion finding inflation rates specific to the cost elements' classes increases the accuracy of the total cost estimate.

2.4. Risk Analysis

While a general definition of risk given by DOD as, "the probability of an undesirable event occurring and the significance of the consequence of the occurrence", Timmerman suggests that the definition should be selected depending on the field of analysis [Timmerman, 1996,2-14]. In this research risk represents the economic risk and defined as the variance of estimated distribution around the expected value [Levary and Seitz, 1990:64]. Risk is created by the uncertainty of the cost elements. In the LCC model outputs, risk is represented by the variance of the estimated NPV. Statistical parameters show estimate of the cost and the interval in which cost is most likely to change.

Three quantitative approaches to risk analysis are highlighted by Stewart [1991;160]. These are the Three Estimate Approach, Monte Carlo Simulation and Decision Tree analysis. The first method is a straightforward approach of assessing the risk by estimating three values of the uncertain cost. Three estimations, optimistic, the most probable and a pessimistic, and the probabilities of associated estimates are employed for risk calculations. Although it is very easy to employ, since it does not give the variation of each estimation, it could mislead the decision maker. Stewart states the importance of this approach for small magnitude investments and the users who know the limitation.

The decision tree analysis allows the investor to evaluate the economic consequences of each event by graphically formulating the events and sequences of the decisions and events.

Monte Carlo approach is the application of the simulation techniques to evaluation of uncertainty and risk. This approach is studied in the next section.

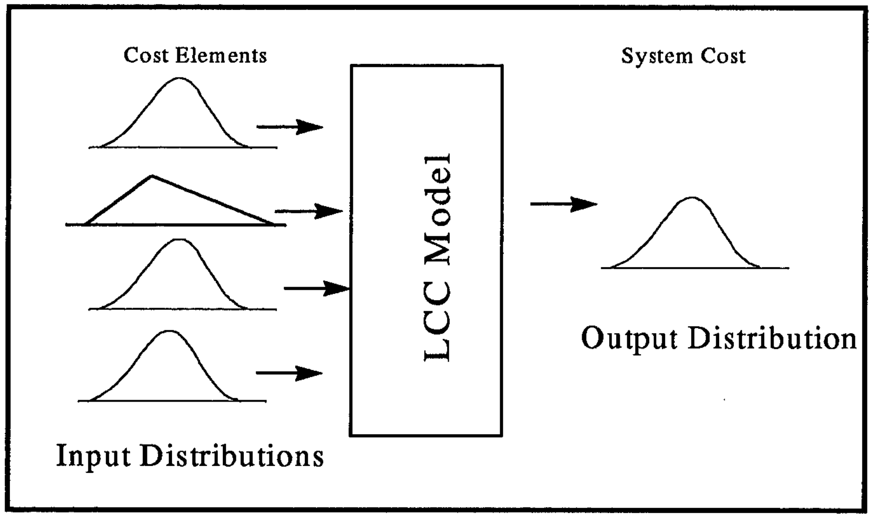
White et al stresses the risk factor approach , the network approach and CER (Cost Estimating Relationships) approaches. [White,1995:18].

2.4.1. Monte Carlo Approach

A key problem in cost estimation is indeed estimating the uncertainty of the total cost of the system of interest. In real systems, input uncertainties have complex interactions with the total cost. After modeling the costs, the Monte Carlo Approach allows one to consider, and take into account, all of the uncertain cost factors simultaneously and repeat this as many times as desired to find an estimation of the final total cost distribution.

The Monte Carlo approach employs the simulation of the costs during the system life. This is accomplished by varying the input parameters or values of the variables of the system and the desired number of replications. In each replication of the simulation after a random draw from the estimated distributions of the variables or cost elements, the NPC is calculated. The main idea behind the approach is estimating single cost elements would be more accurate than estimating total cost of the system at once.

In an LCC model, the source of the uncertainty, assuming the configuration of the systems remains same, is the uncertain cost elements in the model. The relationship between system cost uncertainty and its sources can be described by an input-output relation which is illustrated in Figure 2.3 [Dienemann,1966;6].



Monte Carlo Analysis

Figure 2-9

As seen in the figure, if the input distributions can be defined accurately enough, then the overall uncertainty of the system can be assessed. Describing the probability distributions of the cost elements allows one to generate random samples of corresponding cost elements.

One of the difficulties in application of the Monte Carlo approach is that it requires data to define input distributions accurately enough. In cases where input distributions cannot be derived from historical data, such as in innovative technologies, Dienemann suggests that the analyst must utilize subjective probabilities to describe input uncertainty[1966:13]. He shows a method to estimate the subjective input distribution starting from a three value estimate -lower, most likely and upper- to one of the beta distributions he provides.

2.5. Summary

The literature review indicates that scaling of cost requires historical or price data (for equipment) for different capacities of interest. Finding the scaling factors needs careful work. It is concluded, from the research, that exponential scaling should not be used for higher capacity ratios than five while the regression model scaling should be used in the range in which the model developed. The conditions in which the cost estimation is performed dictates which one of the scaling factors should be used.

For an extended system or project life, inflation is an important factor that affects the cash flow. The main point regarding the inflation effects is use of interest rate. It should be kept in mind that the inflation rate is calculated based on the past year's prices. Therefore, there is always an inherent estimation error for inflation. Another issue is the inflation in the sector that cost estimate is done might be different than general inflation rate.

3. Methodology

3.1. Introduction

The objective of this research is to develop a generic life cycle cost model that incorporates the scaling of cost depending on a variable and cost escalation due to inflation. Based on the literature available, an LCC model is developed that incorporates both scaling and inflation into the model. In this chapter the methods and rationale used in the developed model.

Chapter 3 includes an introduction of the features of the generic model as well as an application of the model to remediation technologies.

3.2. LCC Model

In light of the literature search, a life cycle cost model for innovative technologies is developed. Steps for developing the model, choosing work breakdown structure, using cost elements and scaling factors, and risk analysis techniques are explained in the following sections.

The LCC model consists of an Excel 7 spreadsheet, Visual Basic as Excel 7's macro language and Crystal Ball, a risk analysis tool. A graphic representation of the general structure of the model is given in the figure. The program is menu driven and does not require advanced knowledge about spreadsheet. The macros written in the Visual Basic language an creates interface and prompts user through the steps of cost model. Crystal Ball, used as risk analysis tool is reached through the interface created by Visual Basic macros. The program code is presented in Appendix B.

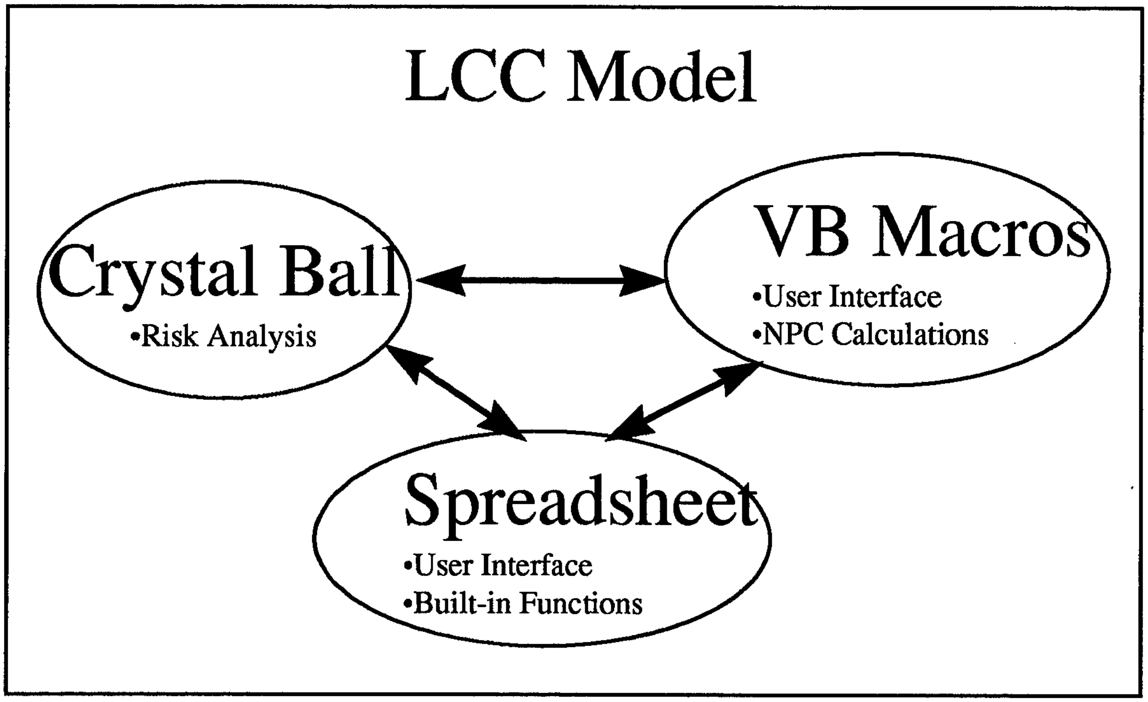


Figure 3-1 LCC Structure

Under this general structure, the model has the following features.

- User defined variables and cost elements
- Built in WBS
- Inflated cost discounting
- Specification of simulation parameters
- Scaling
- User-specified cost correlation
- Sensitivity analysis to cost distriburion

The above features are embodied in the model with the idea of providing the decision maker more ability of analysis.

3.2.1. Work Breakdown Structure

As a starting point of modeling, after studying WBSs of three models and the recommended WBS by FRTR, a WBS was developed. Breaking the cost into meaningful cost elements for planning is considered. For the categorization of activity cost and to cover all activities, the Federal Remediation Technologies Roundtable WBS is used. The reasons for selecting the FRTR's WBS as foundation can be listed as, widest coverage of all activities, standardized list of activities which allows the comparison of cost across the project and the WBS is prepared by interagency group which is formed by the experts of Environmental Protection Agency (EPA), Department of Defense (DOD), Department of Energy (DOE) and Department of Interior.

The WBS presented by White et al is merged into the one which suggested by FRTR . The WBS is available in the model for whom wants to use in his/her specific model. The complete WBS used for cost estimation is given in Appendix A.

3.2.2. Cost Scaling

To develop a model which has a scaleablity feature that allows an estimator to estimate the cost for changing input conditions of the system is a key goal. Research performed shows that scaleablity of cost depends on historical data or known physical relationship. If real data is not readily available then subjective estimation of some cost elements cost may be required.

In the developed model cost scaling is accomplished at the cost element level. Scaling each cost element individually allows correct representation of the effects of scaling variable to each cost element. As a result, it leads to more accurate cost scaling. With the ability of scaling at the cost element level the user of the model can perform a total scaling on the total NPC which is not as accurate as the first approach.

Research dictated the use of one of the following scaling methods: Exponential, Best-Fit equation scaling factors or CER approach. All three methods can be employed in the developed model. Linear, Exponential and Best-Fit equation factors calculations are done by model according to the inputs provided from the user. If user has CER for a cost element he/she can enter CER as value of the cost element. The specific value CER according to the changing variables is calculated.

3.2.3. Monte Carlo Analysis

An LCC estimation of innovative technologies must account for the cost uncertainties, project life and performance. The nature of innovative technologies requires the analysis to treat most of the cost elements as random variables. This requires input analysis of given data to identify the probability distribution of each cost element or parameter.

The Monte Carlo Method is used to simulate each elements cost and overall cost estimation with the variation around point estimator is calculated. At this point sensitivity analysis is required for this simulation process to determine the key cost drivers or parameters.
In the developed model the Crystal Ball is employed to perform the Monte Carlo method.

3.2.4. Modeling

The structure of the model has the variables and the cost elements as starting point. Cost calculations in the model employs the variables and the cost elements to.

Variables are the values used to calculate associated cost elements and defined by the experts. Variables can take value as constant, formula which uses other variables and probability distribution defined in the Crystal Ball. Cost elements are the parts of total cost and each of them has represents different characteristics. In the model, three types of cost elements are introduced to model the money out flow in the life of alternative technologies -trapezoid cost elements

(TCE), recurring cost elements (RCE) and percentage cost elements (PCE). These three types of cost elements can be used to model different cash flows.

For a fair comparison between the alternatives the total cost of the technology with the cash flow during the life of the technology should be discounted to the present time (year 0). In the model this calculations are performed by employing an interest rate (*i*) which should be introduced to the model by the user.

Inflation is another point that can be considered in the calculations. For the alternative technologies with extended life in an economy with high inflation cost estimator should consider the inflation effects. The model calculates the inflation effects for each payment year depending on the given inflation fate (*f*) by the cost estimator

To support the further cost risk analysis Crystal Ball is used for Monte Carlo analysis. Distributions can be assigned to variables or cost elements in the Crystal Ball interface. Program allows user to define empirical distribution depending upon the data as well as to select a distribution from sixteen theoretical distributions

3.3. LCC Model Technology Trains

3.3.1. Train Explanation:

At the Paducah site, depending on the geology and hydrology, the decision makers decided on three operational zones, unsaturated saturated, and aquifer [Kerschus,1997:3-4]. Because of the different geological characteristics of these three zones technology trains are developed. Each train combines the technologies that are considered for corresponding zone. Despite the different features of the zones, experts agree to combine saturated and unsaturated zones into a single zone, The Upper Constructed Recharge System (UCRS). Therefore the trains consist of two technologies associated to the zones. Following table gives the description of the trains and the applicable zones, the UCRS and the Regional Gravel Aquifer (RGA).

Train Number	**Train Description**	
	UCRS	*RGA*
1	2Phase Extraction	DUS
2	2Phase Extraction	Chemical Oxidation
3	6 Phase Soil Heating	Chemical Oxidation

Table 3-1 Tarins

In the construction of the trains, the cost associated with the technologies are modeled and integrated with the other technology. An attempt has been made to incorporate all costs, while leaving any overlapping costs, when integrating these technologies

3.3.2. Technology Summaries:

3.3.2.1. Dynamic Underground Stripping (DUS):

This technology aims to remediate soil and ground water contaminated with organic compounds by employing several technologies [DOE, 1995:1]. The main idea is to heat a volume of soil or ground water to vaporize the contaminant and extract the vapor with the help of vacuum pumps. Three technologies are used together, steam injection, electrical heating and underground imaging.

Steam injection is used permeable subsurface areas [DOE,1995:1]. Injected steam vaporize the contaminant in the soil and force the vapor of contaminant to the vacuum extraction wells.

Electrical Heating is used in less permeable clays and fine-grained sediments [DOE,1995:1]. The goal is same as the steam injection, to vaporize contaminant and force the vapor to the wells.

Underground Imaging which is primarily Electrical Resistance Tomography (ERT) is used to control the cleaning level by delineating the heated areas.

In the remediation of Paducah site, electrical heating should be used for upper two zones(Vadose and Saturated) while steam injection should be applied to the last one, aquifer. Extracted vapor is treated by one of the Off-Gas treatment methods. Cost data is provided from MSE and a test conducted in California in July of 1997.

3.3.2.2. Two Phase Extraction:

Two Phase Extraction, like DUS, aims to remove contaminant by applying air flow through the soil. The main difference is in two phase extraction groundwater and the vapor are extracted simultaneously. Then , after extraction, the water and vapor streams are treated to remove the contaminant. This technology is limited by the depth to which it can be applied.

Data provided by MSE collected from the applications by XEROX, Radian and HGI. Performance curves were from a Xerox site and a private site operated by Radian[MSE,1997:13].

3.3.2.3.In-Situ Chemical Oxidation:

Chemical Oxidation is used to remediate the both soil and groundwater contaminated with organic substances like dnapl and lnapl. Hydrogen peroxide is used to produce carbon dioxide and water according to the Fenton's reaction. With this reaction the organic contaminants are changed into harmless state.

The work from MSE shows that the costs associated with in-situ chemical oxidation can be represented by the model which has independent variables, mass of the contaminant, number of injection wells and the lithology of the site. The cost model is given as following [MSE 1997:5].

Cost = 4 (Mass) + 4789(# of Injection wells)+ 22996 (Grain Size) - 29885

In the model, the capital cost of the technology is calculated from the effects of number of injection wells and grain size while annual operating cost is calculated by effect of mass of dnapl

3.3.2.4.6 Phase Extraction:

Six Phase Soil Heating (SPSH) is a new technology that is developed to overcome the limitations of soil vapor extraction requires certain conditions to be effective. The two conditions are that the soil must be permeable and the compounds must be volatile. In the application of the technology, six electrodes are placed in hexagonal shape and seventh one is placed in the center. When electricity is applied at the increasing heat the vapor pressure of the contaminant increases and the vapor is vacuumed out by center pipe.

The applications show that the technology gives good results for low permeability soils and semi-volatile contaminants.

Cost data provided by MSE was obtained from Pacific Northwest National Laboratory (PNNL), which is the developer of the technology.

3.3.3. Train #1: Two Phase Extraction & Dynamic Underground Stripping

This alternative was created to minimize the possible dangerous surface effect of DUS, a stream breakout The train includes two-phase extraction for the UCRS and dynamic underground stripping for RGA.

As mentioned in the technology summaries, these two technologies primarily are close. Contacts with expert show that extra extraction wells are the only addition to dynamic underground stripping required to collect the vapor cannot be collected by DUS wells.

Assumptions,

- Capital cost, operating and off gas costs of DUS remain as the technology is applied to all zones. The reason is the unit cost of cleaning collected vapor becomes lower.
- Capital costs elements, Design and Permitting , Regulatory Negotiation/Public Relations and Electrical services given in the MSE model are excluded with the assumption of they are already accounted in DUS cost calculations.

Two phase extraction is applied to UCRS and DUS is applied to the RGA zone. The cost breakdown structure used in the model is given in the Figure 3-2.

Cost Breakdown Structure

A. Capital Cost

1. Capital Cost of DUS

2. Capital Cost of Two Phase

a) Design and Permitting

b) Regulatory and Negotiations and Public Relations

c) Skid Mounted Vacuum System

d) Piping

e) Electrical Service

f) Construction Cost

B. Operations and Maintenance Cost

1. Operations DUS

2. OFF-Gas

Figure 3-2 DUS-2Phase

3.3.4. Train#2 Two Phase Extraction & In Situ Chemical Oxidation

The two technology integrated in the model with the assumption of independence. It is assumed that in their application to different zones the cost elements do not overlap. Under the general assumptions the cost breakdown structure is given as following.

Two phase method is applied to The UCRS and In situ chemical is applied to the RGA. The following is the cost breakdown structure of the model.

Cost Breakdown Structure

A. Capital cost

   1. Two Phase Capital Cost

      a) Design and Permitting

      b) Regulatory and Negotiations and Public Relations

      c) Skid Mounted Vacuum System

      d) Piping

      e) Electrical Service

      f) Carbon Vessels

   2. Chemical Oxidation Capital Cost

      a) Cost Injection Wells

      b) Capital Drain

B. Operations and Maintenance Cost

   1. Two Phase Ops and Main. Cost

      a) Electric Cost

      b) Off-Gas Cost

   2. Chemical Oxidation Capital Cost

      a) Chemical Operations Cost

Figure 3-3 2Phase-Chemical Oxidation

3.3.5. Train # 3: 6 Phase Soil Heating & In Situ Chemical Oxidation

The same assumptions as train#2 are made for train#3. These two technology are assumed not to effect each other's cost. So the total cost is calculated as the sum of the cost of application to the two different zones. The cost breakdown structure given in Figure 3- 4 used in the model.

6 Phase soil heating is applied to the UCRS while in-situ chemical oxidation is applied to the RGA zone.

3.4. Simulation Runs

Simulation runs are designed to get more information about the parameters of interest. The estimate of mean NPC of the alternative remediation trains are the ones come firs. The other parameter of interest is the mean remediation time of each train. To support the project risk analysis process the distributions of these two parameter are also developed.

The model runs are performed in two different pattern. In the first one the volume of the contaminant is the only uncertainty introduced to the model. The random variable of volume is generated from the distribution which is provided by the experts. The cumulative distribution of the volume in gallons is shown in Figure 3-5.

In the first part, models for each technology train are run for different levels of possible performance which can be defined as the percentage of the volume removed or remediated. Even though the volume of the contaminant is the biggest uncertainty, the performance also is not known with certainty. Therefore the models are run for performance levels, 50%, 60%,70%,80%,90% and 99.99% which can be accepted as 100%.

Cost Breakdown Structure

A. Capital Cost

   1. Phase Capital Cost

      a) Design Cost

      b) Mobilization

      c) Demobilization

      d) Closure

      e) Array Cost

   2. chemical Oxidation Capital Cost

      a) Injection Wells Cost

      b) Capital Drain

B. Operations and Maintenance Cost

   1. Phase Ops and Main Cost

      a) Off-Gas Cost

      b) Maintenance Cost

      c) Energy Cost

      d) Equipment Lease

   2. Chemical Ops and Main. Cost

      a) Ops Chemical Cost

Figure 3-4 6Phase-Chemical Oxidation

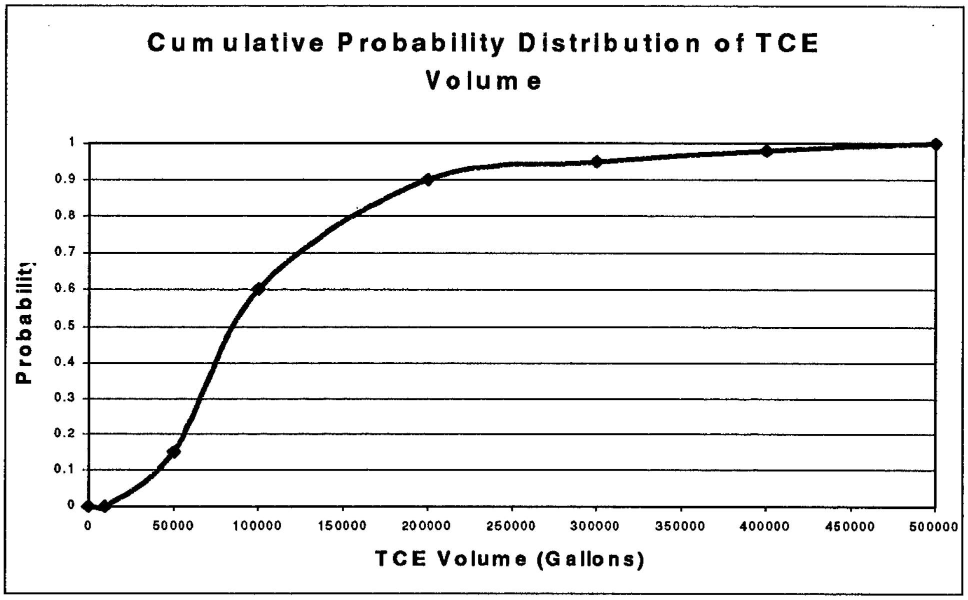


Figure 3-5 Contaminant Distribution

The other important uncertainty about the alternative technologies is performance level. Even though the there are calculations for 100% removal, experts are agree that it such a performance is impossible. Thus, for more realistic analysis, experts estimated performance of DUS-2 Phase train (Train #1) by using Pearson Tukey Estimation of the possible performance levels as given in the Table 3-2. This performance estimates are used for the other two trains to allow comparison between the alternative trains.

Actually performance level can be any number from 0% to 99.99% and not only two levels, 70% and 90%, are possible. With the same three point estimate of performance level triangular distribution is used to make continuous analysis of changing performance levels.

	Probability	Performance
Minimum	0.185	70
Most Likely	0.63	90
Maximum	0.185	90

Table 3-2 Performance Level Probabilities

Number of trials are determined by the input distribution variable, only source of variability, and available time. Even though variance gets smaller as the iteration number increase, the time required to run high number of iterations is considerably high. Therefore number the of replications for each model was set at1000.

4. Results of Model Runs

The output of the model is analyzed to support the decision process of selecting from among the alternative remediation technologies. The following table shows the alternatives and the investigated ranges. For each performance level the number of replication is 1,000.

Alternatives	Performance Level	Volume
Train#1 (DUS-2Phase) Train#2 (2Phase-Oxidation) Train#3 (6Phase-Oxidation)	50% 60% 70% 80% 90% 100% 70%-90%	10000 - 500000 (Gallons)

Table 4-1 Model Runs

The first evaluated data is the product of the model runs for the performance levels ranging from 50 to 100%. The Net Present Costs (NPC) for all levels are compared and the confidence intervals for the means are calculated and compared. In addition, the mean and the distribution of the NPC are estimated.

4.1. Net Present Cost (NPC) Curves

The models are run under the assumption of one random variable, contaminant volume. The only changing value in each iteration of the model is the number of gallons of pollutant. In Figure 4-1 gives the NPC value graphed against the volume of contaminant for performance level of 90%, since this is the target level desired by the Paducah team. The graph shows that the

Train#1 (DUS-2PHASE) has lower NPC for all possible values of contaminant volume. On the other hand to gain more information about the values of Train#2 and Train #3 further analysis is conducted since the values are close. The curve given in Figure 4-1 shows the spread of cost depending on contaminant volume.

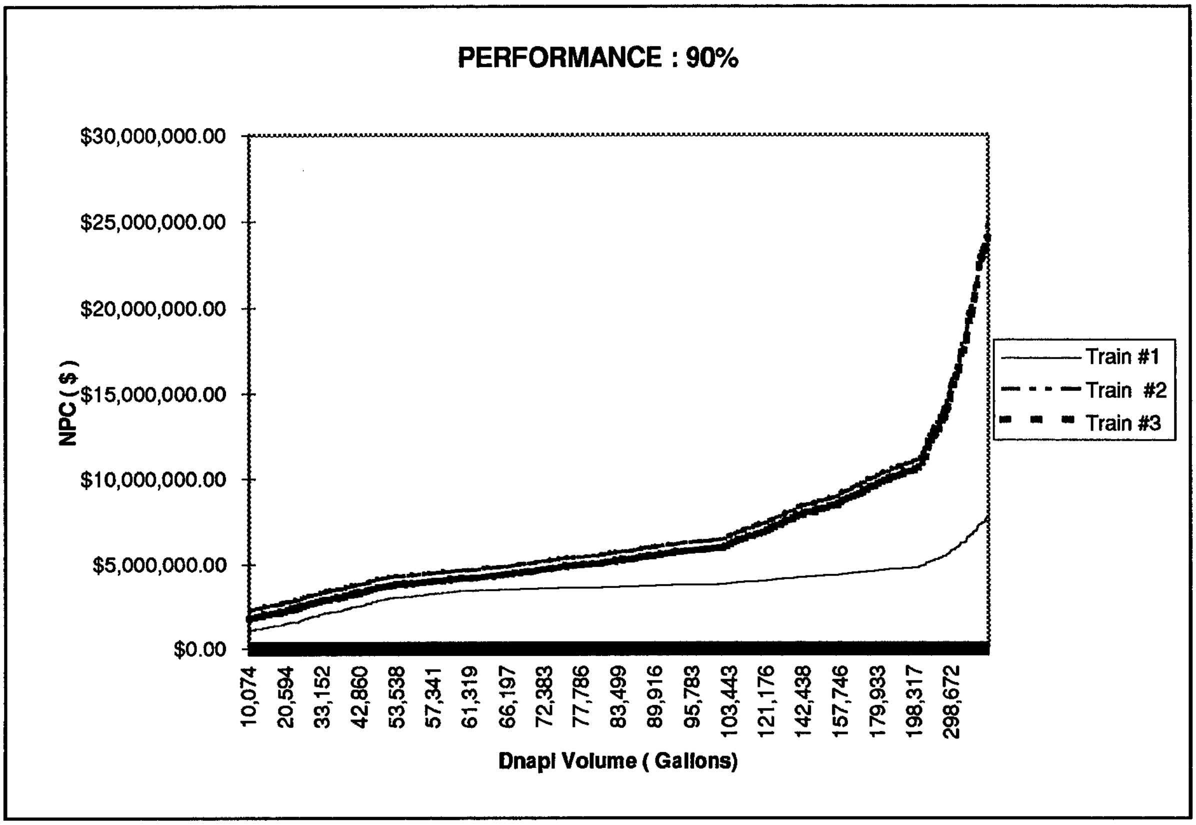


Figure 4-1 NPC vs. Contaminant Volume

4.2. NPC Estimates

Estimated means of the alternatives for different levels of performance is provided in Figure 4-2. The values suggests that Train #1 would be preferred at all levels of performance. Train #2 and Train#3 have close mean values which is requires further analysis. Figure 4-3 shows 95% confidence intervals of Train#2 and Train#3 for different performance levels.

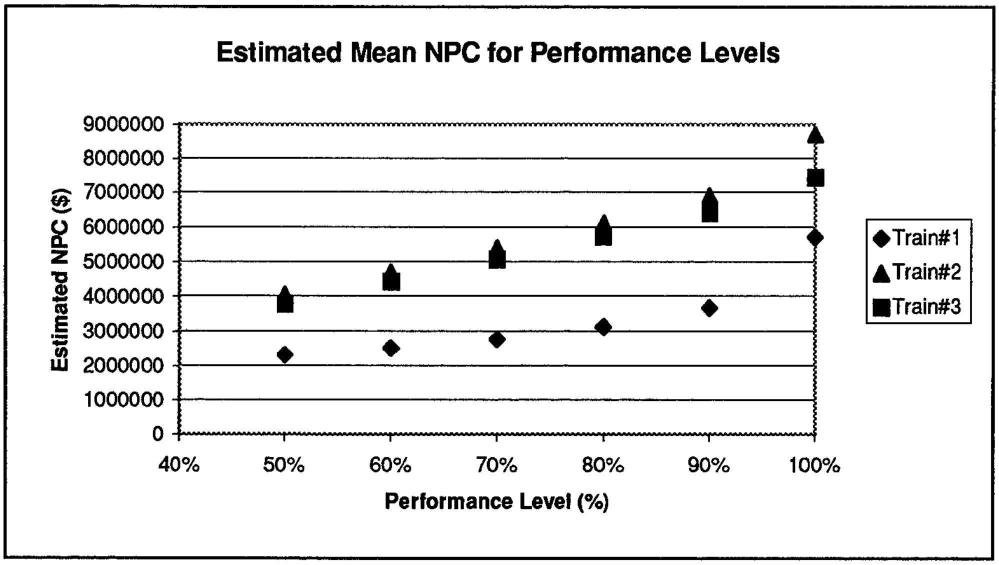


Figure 4-2 Estimated NPC at Performance Levels

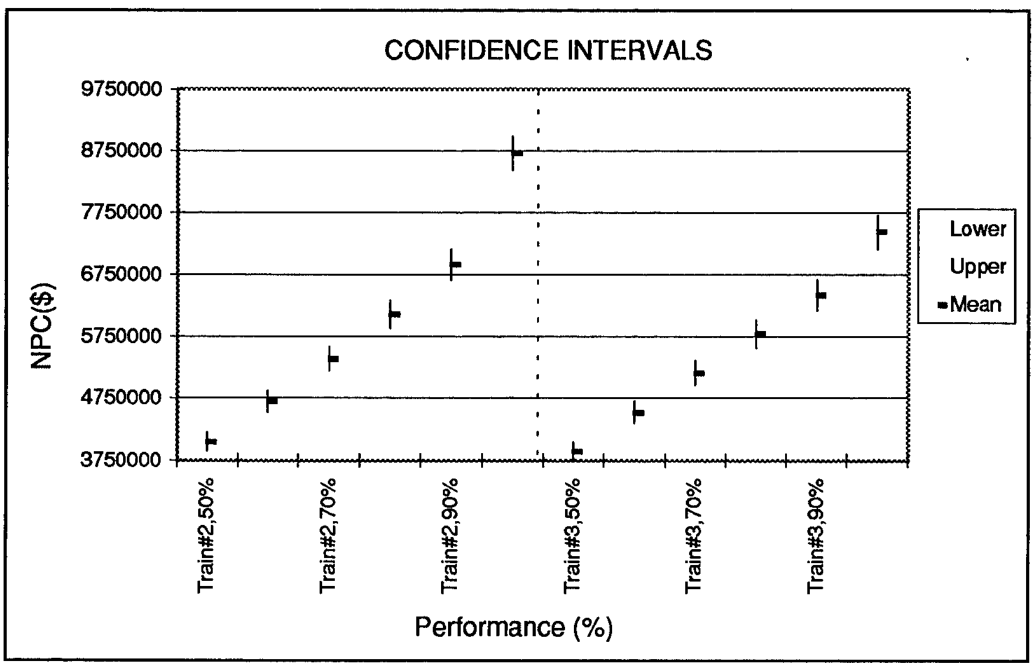


Figure 4-3 Train#2 and Train #3 NPC Means Confidence Intervals

To further investigate the relations a paired-t test is conducted for the confidence intervals of the difference of means. Since there are three alternatives the confidence levels are constructed at level 1-α/(k(k-1)/2 where k =3 [Law and Kelton, 1991: 594].

The hypotheses,

Train#1- Train#2 H_o: $\mu_1=\mu_2$ H_a: $\mu_1\neq\mu_2$

Train#1- Train#3 H_o: $\mu_1=\mu_3$ H_a: $\mu_1\neq\mu_3$

Train#2- Train#3 H_o: $\mu_2=\mu_3$ H_a: $\mu_2\neq\mu_3$

where μ_i is the sample mean for train i.

The results of the hypothesis test are given in Table 4-2. None of the confidence intervals for (μ_i- μ_j) includes zero. We are unable to conclude there is no difference in means and accept the alternative hypothesis that a difference exists. Train #1 has the lowest expected NPC, Train#3 comes second and the Train #2 has highest expected cost.

	Mean	Half Width
Train#1-Train#2	-3227867.722	1569
Train#1-Train#3	-2729364	225750
Train#2-Train#3	498503.8	0.004

Table 4-2 Confidence Intervals for 90%

4.3. NPC and Time Distributions

NPC and time distributions are generated by introducing the performance level as second random variable distribution to the model. Two different approaches are followed. First the distribution is estimated by Pearson-Tukey estimation as stated by experts. Secondly, a triangular distribution is used to estimate the distribution of the performance.

Table 4-3 shows the mean and half width of the 95% confidence interval of the mean for both cases. As it can be predicted, the confidence interval of the means in the replications that uses the triangular distribution is smaller. Even though it gives better insight about the variation of the mean, the decision maker should be comfortable with using the triangular distribution.

	Pearson-Tukey		Triangular	
	Mean	Half Width	Mean	Half Width
Train#1	3,574,824	75,889	3,356,547	70,331
Train#2	6,860,686	259,940	6,525,331	245,729
Train#3	6,399,648	258,982	6,166,241	247,749

Table 4-3 Means and Half Widths ($)

Time to protection is the other factor that is evaluated in remediation technology selection. The distribution of the total time required for each remediation technology train is a logarithmic function of the performance level input, according to the MSE model. The time distribution for each train is found for the two cases, The Pearson Tukey estimate and the triangular distribution estimate of performance level.

With the Pearson-Tukey estimation, there are two possible levels of time. The proportion of the possible time levels for each train is given in Table 4-4.

	20.5%	79.5%
Train#1	1.17	1.33
Train#2	2.98	5.70
Train#3	0.28	0.54

Table 4-4 Time Levels for Trains (Year)

Triangular estimation of performance level, if an accurate representation of the variation, allows information to be gleaned about the distribution of time required for application of each technology train. The mean and confidence interval of the expected mean of time for each alternative train is given in Table 4-5. From both estimation method, train#3 has lowest mean for time and train#2 has highest.

	Mean	Half Width
Train#1	1.26	0.003
Train#2	4.458	0.042
Train#3	0.4197	0.004

Table 4-5 Mean and Half Width of Time

With the information above a dominance graph for the alternatives is given in Figure 4-4. The graph shows that no one alternative dominates. Train#2, on the other hand, has the highest expected cost and highest expected time, which are undesirable attributes.

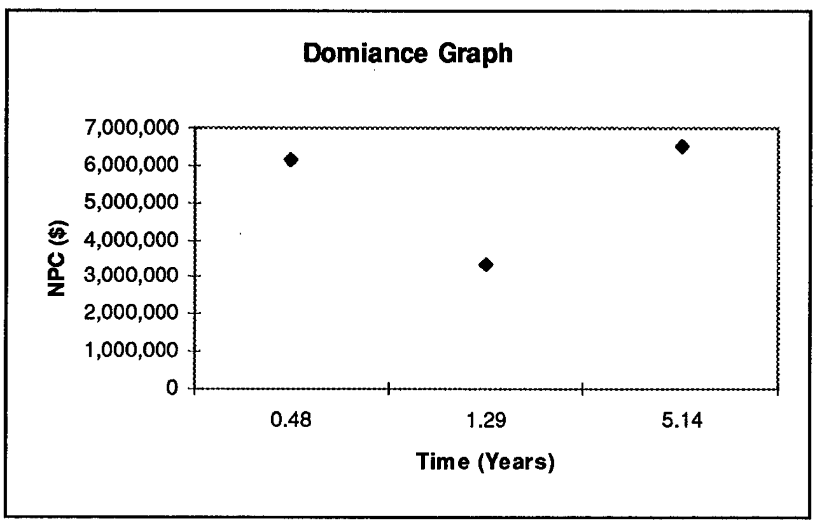


Figure 4-4 Dominance Graph

4.4. Summary

In the analysis of the trial sessions, the NPC of each train and the time required for the application of each train is evaluated. First the means for the NPC are estimated and compared by using paired-t tests. The tests showed that the difference between the means are statistically significant. Train #1, Dynamic Underground Stripping with 2 Phase, is the dominating alternative when cost is the only consideration. Second the times required for application of the technology trains are estimated. The expected time for Train #3, 6Phase with Chemical Oxidation, has lowest expected time while Train#2 has highest expected time. Finally, a dominance graph shows that, there is no single dominating technology train while the least desirable alternative is Train#2, Two Phase Extraction.

5. Conclusion

LCC analysis is a powerful tool for investigating the costs of competing systems. The quality of the estimate depends on the features of the LCC model and its ability to utilize data developed by cost engineering. In this study, desired features of the an LCC model were reviewed and outlined. In addition to identifying desired features, the study focused on incorporating cost scaling and inflation in cost estimating effort. The conclusion drawn from this research and the conclusion of the LCC application to innovative remediation technologies are presented in the following sections.

5.1. Scaling

The efforts in scaling cost of a system for different capacities are, generally, focused on capital cost of the system. Generally this is because most of the time operating and maintenance cost is a known function of production volume and research and development cost is independent from capacity of the system.

The methods for cost scaling can be listed as linear scaling, exponential scaling and scaling with regression models. The selection of the method depends on the desired accuracy and the data that represents the cost behavior of the cost element. It should be kept in mind that each of these methods have shortcomings which affect the accuracy of the estimation.

Another important issue in performing cost scaling that influences the accuracy of the estimation is the level of the scaling. Estimating the cost of a single cost elements' value for different capacities is more accurate than estimating system's total cost. This suggests having the ability to employ different scaling methods for each of the cost elements according to the nature of relation between the cost element and the capacity. Scaling method should be performed, if possible, at the level of cost elements.

5.2. Inflation

The approaches to handle inflation effects in cost estimating have one common foundation, finding the cost of system in terms of the present purchase value of money. One of the approaches suggests just to ignore the inflation when estimating the future rate of inflation. While this may be effective in economies with low inflation rates, it is not appropriate for all settings. When estimating the cost of a system with an extended life, it is very difficult to estimate the rate of inflation.

When estimating the cost with inflation effects, inflation rates of special products or material should be estimated differently than with single common price indexes. One should never forget that the common indices of inflation rates are weighted average of all price increases. They may not reflect the rate of specific elements. Since the accuracy of inflation rate estimate decreases for extended years, the rate of inflation should be chosen carefully.

5.3. Remediation Technologies

The LCC analysis of alternative remediation technologies was conducted to support the risk analysis and decision process. Therefore the distributions of NPC and time are generated as outputs of the LCC model.

Between the three alternative technology trains, there is no alternative that dominates the others although Train #2, 2 Phase Extraction and Chemical Oxidation, is dominated by the other two alternatives. This suggests the elimination of the Train#2, if NPC and the Time were the only attributes to consider.

5.4. *Recommendations for Follow on Studies*

During the research there were several issues encountered that were not among the objectives of this study and could be topics for further analysis.

5.4.1. Inflation.

In this study the ways to consider the inflation effects in cost estimating is reviewed. Estimating an inflation rate and using different price indexes for special equipment are the important issues which effects the accuracy of the inflation.

5.4.2. LCC Model

The application of the LCC model for WAG 6 Site in Paducah, Kentucky is performed with the data provided, which is very limited. More accurate cost estimation of the technology alternatives would be valuable. Further research should collect more detailed data, would lead to more accurate estimation of remediation costs.

With more detailed data, further research and sensitivity analysis on the cost elements which are considered as important, could give more insight to decision maker to develop new strategies in decision process.

The model was developed in a way that, it allows LCC estimations in any field of interest. The only change in model will be the WBS. Cost estimations for different remediation projects and even for different areas, such as weapon system acquisitions, can be accomplished by employing the WBS specifically developed for the project.

Appendix A: Work Breakdown Structure

I. Research and Development Cost

II. Capital Cost

A. Site Preparation Cost

1. Site clearing
2. Site access
3. Borehole drilling
4. Permits and licensing
5. Fencing
6. Heat, gas, electricity, water for site prep

B. Structures Cost

1. Building
2. Platforms
3. Equipment structures
4. Equipment shed. Warehouse

C. Process equipment Cost

1. Technology parts and supplies
2. Materials and supplies needed to make

D. Non-Process equipment Cost

1. Office and administrative equipment
2. Data processing and computer equipment

III. Operations and maintenance cost

A. Direct Labor Cost

1. Direct labor to operate equipment
2. Direct labor supervision
3. Payroll charges
4. Contract labor charges
5. Direct labor for contract

B. Direct Materials Cost

1. Consumable Supplies

2. Process materials & chemicals
3. Utilities
4. Fuels
5. Replacement parts

C. Overhead Total Cost

1. Plant and equipment maintenance
2. Liability insurance
3. Shipping charges
4. Equipment rental for operations
5. Vehicle supplies and insurance
6. Transportation

D. General and Administrative Cost

1. Administrative labor
2. Marketing
3. Communications
4. Project management
5. Travel
6. Interest expenses

E. Other and Miscellaneous Cost

1. Maintenance contract for equipment
2. Waste disposal
3. Health and safety
4. Contract services
5. Other

IV. Disposal and Phase-out Cost

A. Site Closure
B. Decontamination and Decommissioning (D&D)
C. Transportation
D. Disposal
   1. Commercial Disposal
   2. Other than Commercial
E. Monitoring
F. Site Restoration
G. Demobilization
H. Other

Appendix B: Visual Basic Code Modules

```
""LCC Model VB Modules
""Main Menu Module
""Declarations of  object variables

Public DATASheet As Worksheet
Public GenDialog As DialogSheet




Public ButtonClicked As String
Public DBoxOK As Boolean

Dim Filename As String
Dim Filter As String
Dim FilterIndex As Integer
Dim Title As String
Dim ExitOk As Boolean
Dim Sel As String
''''''''''''


""This  routine runs the main menu and prompts user
""to select from the menu items

Sub RunMainMenu()


   Application.Calculation = xlAutomatic
   DBoxOK = True
'  Loop until the main dialog is cancelled
   Do While DBoxOK

     DBoxOK = ThisWorkbook.DialogSheets("MainDialog").Show

       If Not DBoxOK Then End

       Select Case ButtonClicked
          Case "First":  FirstSub
          Case "Second":  SecondSub
```

```
        Case "Third":  ThirdSub
       'Case "Fourth":  Runsim
        Case "Fifth":  CloseLCC
        Case "Sixth":  DataSave (ActiveWorkbook.Name)
        Case "SimSet": FourthSub
      End Select

   Loop

End Sub

''''''''''''''

Sub CheckButton()
   ButtonClicked = Application.Caller
End Sub
''''''''''''''
' This routine simply updates the lists of variables and cost elements defined in model
Sub FirstSub()
CopyLists

End Sub

''''''''''''''
'' Prompts the user create new model

Sub SecondSub()

   AssignNumbers
   ClearData
   ActiveWorkbook.Sheets("costs").Range("E2").Value = InputBox("Name Of the Technology")
   ActiveWorkbook.Sheets("costs").Range("E4").Value = InputBox("Zone")
   Rate
   EditMod (1)

End Sub

''''''''''''''
''' Shows edit menu and prompts user  to update existing model
Sub ThirdSub()
   EditMod (2)
End Sub

''''''''''''''
''This module allows user to run model deterministically, and input the
''simulation settings
```

```
Sub FourthSub()
   ThisWorkbook.DialogSheets("RUNMenu").Show

   Select Case Sel

       Case "EditCalculate": Calculate
       Case "EditSetting": Application.Run Macro:="CB.RunPrefs"
       Case "Costs": ActiveWorkbook.Worksheets("Costs").Activate
       Case "Run": Runsim

     End Select

End Sub
'''*********************************
"" Runs simulation
Sub Runsim()

   ActiveWorkbook.Sheets("Costs").Activate
   ButtonStop
   Application.Run Macro:="CB.RunRun"
   Exit Sub

End Sub

''******


Sub Runcont()
   Sel = Application.Caller
End Sub

''' Asks for saving file and Close
Sub CloseLCC()
   Ans = MsgBox("Do you want to close LCC Model?", vbYesNo + vbQuestion)
   If Ans = vbYes Then
     ActiveWorkbook.Close
   End If
End Sub
'*************************************
"This subroutine saves the active file under chosen name.


Sub DataSave(OldFileName)

'  Set the dialog box caption
```

```
   Title = "SaveAs"
   Call Default_Attributes
   Filename = Application.GetSaveAsFilename(OldFileName, Filter, FilterIndex, Title)
   If Filename = "" Then
     MsgBox "File not saved"
     Exit Sub
   End If

   ActiveWorkbook.SaveAs Filename

End Sub

'****************************************
'Assigns the default attributes to save the file.

Sub Default_Attributes()
'  Set up list of file filters
   Filter = "Excel Files (*.xls),*.xls," & _
          "Text Files (*.txt),*.txt," & _
          "Data Files (*.dat),*.dat," & _
          "All Files (*.*),*.* "
'  Display *.* by default
   FilterIndex = 5
End Sub
'' ** End of Main Menu Module
'' This module includes the subroutine that gets variables from user.

Public NumberVar As Integer

Sub VarInputRout()
   Dim Value_Cells As Range

   Set Value_Cells = ActiveWorkbook.Worksheets("DATA").Range("E5:E500")
   Set VarInDialog = ThisWorkbook.DialogSheets("VarInput")

   InputCont = True

  ' Dim InputCont As Boolean

   i = 7
   NumberVar = 3   ' Don't Forget

   Do While InputCont

     VarInDialog.EditBoxes("VarEditName").Text = ""
```

```
    VarInDialog.EditBoxes("VarEditVal").Text = ""

 TryAgain:
    InputCont = VarInDialog.Show

    If Not InputCont Then
     CopyLists
     Exit Sub
    End If


    VarName = VarInDialog.EditBoxes("VarEditName").Text
    VarValue = VarInDialog.EditBoxes("VarEditVal").Text
    If (VarName = "" And VarValue = "") Then
      conf = vbOKOnly + vbCritical
      Msg = "You must enter name and value of variable." & Chr(13)
      Msg = Msg & "Please check your variable and enter again. "
      Ans = MsgBox(Msg, conf)
      GoTo TryAgain
    End If
    On Error GoTo ErrorHandler

    For Each cell In Value_Cells

      If cell.Value = "" Then
        cell.Value = VarName
        cell.Offset(0, 1).Name = VarName
        cell.Offset(0, 1).Formula = VarValue

        Exit For
      End If

    Next

  Loop
  Exit Sub
ErrorHandler:
  conf = vbOKOnly + vbCritical
  Msg = "The value is not valid." & Chr(13)
  Msg = Msg & "Please check your variable and enter again. "
  Ans = MsgBox(Msg, conf)
  GoTo TryAgain

End Sub
'***** End of variable input module
```

```
"""""This Modules clears the existing names if user wants to create
"""""" new model and gets Performance, Inflation Rate,
"""""" Interest Rate, Performance-Time function

"""" Deletes existing DATA and Creates the new DATA
Public DATASheet As Worksheet
Dim Button As String

Sub ClearData()

   Set DATASheet = ActiveWorkbook.Worksheets("DATA")

   DATASheet.Range("A5:HR500").Clear
   Do While ActiveWorkbook.Names.Count > 0
     ActiveWorkbook.Names(1).Delete
   Loop


End Sub

"""" Promts user to enter Performance function and the three basic variable,
"""" Interest rate, Inflation Rate, and desired
"""" Performance level.
Sub RateCheck()
   Button = Application.Caller
End Sub
Sub Rate()
   Set GenDialog = ThisWorkbook.DialogSheets("Performance")
   Set GenDialog2 = ThisWorkbook.DialogSheets("Rate")
   Set DATASheet = ActiveWorkbook.Worksheets("DATA")
   Set costSheet = ActiveWorkbook.Worksheets("Costs")
   GenDialog.EditBoxes("PerEdit").Text = "= Performance"
Back:
   Button = ""
   GenDialog.Show
   If Button = "Cancel" Then RunMainMenu

   DATASheet.Range("$C$5") = GenDialog.EditBoxes("PerEdit").Text
   DATASheet.Range("$B$5").Value = "Time"
   DATASheet.Range("$B$6").Value = "ProjectYear"
   DATASheet.Range("$E$5").Value = "InterestRate"
   DATASheet.Range("$E$6").Value = "InflationRate"
   DATASheet.Range("$E$7").Value = "Performance"
   DATASheet.Range("$F$5") = GenDialog2.EditBoxes("InterEdit").Text
```

```
   DATASheet.Range("$F$6") = GenDialog2.EditBoxes("InfEdit").Text
   DATASheet.Range("$F$7") = GenDialog2.EditBoxes("PerEdit").Text
   Button = ""
   GenDialog2.Show
   Select Case Button
       Case "Cancel": RunMainMenu
       Case "Back": GoTo Back
   End Select

   DATASheet.Range("$F$5") = GenDialog2.EditBoxes("InterEdit").Text
   DATASheet.Range("$F$6") = GenDialog2.EditBoxes("InfEdit").Text
   DATASheet.Range("$F$7") = GenDialog2.EditBoxes("PerEdit").Text
   Names.Add "InterestRate", "=DATA!$F$5"
   Names.Add "InflationRate", "=DATA!$F$6"
   Names.Add "Performance", "=DATA!$F$7"
   Names.Add "Time", "=DATA!$C$5"
   DATASheet.Range("$B$6").Name = "ProjectYear"
   costSheet.Range("D7").Name = "NetPresentCost"
   costSheet.Range("D8").Name = "AnualCost"
   costSheet.Range("D10").Name = " NPVCapital"
   costSheet.Range("D11").Name = " NPVOpMain"
   costSheet.Range("D12").Name = " NPVResDev"
   costSheet.Range("D13").Name = " NPVPhOut"
   costSheet.Range("E15").Value = "No Scaling"

End Sub


'''''End of the Create Module
'''''*****************************************************
''''' This module includes all the functions that calculates the cash outstream.

'''' Public Time As Integer

Public DATASheet As Worksheet
Public costSheet As Worksheet
Sub Precal()
   DATASheet.Range("C6").Value = "0"
   Call Calculate
End Sub

Sub Calculate()
   Set costSheet = ActiveWorkbook.Worksheets("Costs")
   Set DATASheet = ActiveWorkbook.Worksheets("DATA")
```

```
  Dim Totalyears As Integer

  Application.Calculation = xlAutomatic
  Totalyears = Int(DATASheet.Range("Time").Value) + 1

  costSheet.Range("A20:O" & CStr(2000 + Totalyears)).Clear

  For Projyear = 0 To Totalyears

  DATASheet.Range("ProjectYear") = Projyear

  DATASheet.Rows(10).Calculate
  DATASheet.Rows(19).Calculate
  DATASheet.Rows(27).Calculate
  costSheet.Cells(20 + Projyear, 2) = Projyear
  Call Tce(Projyear)
  Call Rce(Projyear)
  Call Pce(Projyear)
  Call NPC(Projyear, DATASheet.Range("F5"))
  Next Projyear
  If Totalyears > 1 Then
    IntRate = DATASheet.Range("InterestRate").Value
    AnYear = DATASheet.Range("Time").Value
    costSheet.Range("AnnualCost").Value = costSheet.Range("NetPresentCost").Value *
IntRate _ *(1 + IntRate) ^ AnYear / ((IntRate + 1) ^ AnYear - 1)
  Else
    costSheet.Range("AnnualCost").Value = costSheet.Range("D7").Value
  End If

  Application.Calculation = xlAutomatic

End Sub
''*******************************

Sub Tce(Year)

 Dim TValue As Single
 Dim TStartYear As Single
 Dim TPhaseIn As Single
 Dim TConstant As Single
 Dim TPhaseout As Single
 Dim TInf As Single

 Set DATASheet = ActiveWorkbook.Worksheets("DATA")
 Set Tce_Cells = DATASheet.Range("H5:H250")
```

```
 Inf = DATASheet.Range("F6")


 For Each cell In Tce_Cells

    If cell.Value = "" Then Exit Sub


      TScale = cell.Offset(0, 1)
      TValue = cell.Offset(0, 2)
      TStartYear = cell.Offset(0, 3)
      TPhaseIn = cell.Offset(0, 4)
      TConstant = cell.Offset(0, 5)
      TPhaseout = cell.Offset(0, 6)
      Cat = cell.Offset(0, 7)
      Select Case Cat
           Case "Capital_Cost":
               Sheets("Costs").Cells(Year + 20, 6) = Sheets("Costs").Cells(Year + 20, 6) + _
TceAnn(Inf, Year, TScale, TValue, TStartYear, TPhaseIn, TConstant, TPhaseout)
          Case "R&D_Cost":
               Sheets("Costs").Cells(Year + 20, 12) = Sheets("Costs").Cells(Year + 20, 12) + _
TceAnn(Inf, Year, TScale, TValue, TStartYear, TPhaseIn, TConstant, TPhaseout)
          Case "Operations&Maintenance_Cost":
               Sheets("Costs").Cells(Year + 20, 9) = Sheets("Costs").Cells(Year + 20, 9) + _
TceAnn(Inf, Year, TScale, TValue, TStartYear, TPhaseIn, TConstant, TPhaseout)
          Case "Phase_out_Cost":
               Sheets("Costs").Cells(Year + 20, 15) = Sheets("Costs").Cells(Year + 20, 15) + _
TceAnn(Inf, Year, TScale, TValue, TStartYear, TPhaseIn, TConstant, TPhaseout)
    End Select

 Next cell
End Sub

Function TceAnn(Inf, Year, ScFac, Value, StartYear, PhaseIn, Constant, Phaseout)
 Dim A As Single, B As Single, C As Single
 A = 0
 B = 0
 C = 0
 Annual = 0
 A = StartYear + PhaseIn
 B = A + Constant
 C = B + Phaseout

 If StartYear < Year And Year < A Then
```

```
    Annual = Value / PhaseIn * (Year - StartYear) * (1 + Inf) ^ Year
  ElseIf A <= Year And Year <= B Then
    Annual = Value * (1 + Inf) ^ Year
  ElseIf B < Year And Year < C Then
    Annual = Value / Phaseout * (C - Year) * (1 + Inf) ^ Year
  End If

  TceAnn = Annual * ScFac
End Function
''''''''*******************


Sub Rce(Year)

  Dim RScale As Single
  Dim RValue As Single
  Dim RStartYear As Single
  Dim RPhaseIn As Single
  Dim RConstant As Single
  Dim RPhaseout As Single
  Dim RInf As Single

  Set Rsheet = ActiveWorkbook.Worksheets("Costs")
  Set Rce_Cells = DATASheet.Range("Q5:Q250")
  Inf = DATASheet.Range("F6")

  i = 4

  For Each cell In Rce_Cells

    If cell.Value = "" Then Exit Sub
      i = i + 1

     RScale = cell.Offset(0, 1)
     RValue = cell.Offset(0, 2)
     RStartYear = cell.Offset(0, 3)
     RNumpay = cell.Offset(0, 4)
     RSkip = cell.Offset(0, 5)
     Cat = cell.Offset(0, 6)
     Select Case Cat
         Case "Capital_Cost": Rsheet.Cells(Year + 20, 6) = Rsheet.Cells(Year + 20, 6) + _
RceAnn(Inf, _ Year,   RScale, RValue, RStartYear, RNumpay, RSkip)
         Case "R&D_Cost": Rsheet.Cells(Year + 20, 12) = Rsheet.Cells(Year + 20, 12) + _
RceAnn(Inf, _ Year, RScale, RValue, RStartYear, RNumpay, RSkip)
```

```
        Case "Operations&Maintenance_Cost": Rsheet.Cells(Year + 20, 9) = Rsheet.Cells(Year
_ + 20, 9) _  + RceAnn(Inf, Year, RScale, RValue, RStartYear, RNumpay, RSkip)
        Case "Phase_out_Cost": Rsheet.Cells(Year + 20, 15) = Rsheet.Cells(Year + 20, 15) + _
RceAnn(Inf, _  Year, RScale, RValue, RStartYear, RNumpay, RSkip)
    End Select

 Next cell
End Sub

Function RceAnn(Inf, Year, ScFac, Value, StartYear, Numpay, Skip)
 Ink = 0
 Annual = 0
 For i = 1 To Numpay
  If Year = StartYear + Ink Then
     Annual = Value * ScFac * (1 + Inf) ^ Year
     Exit For
  End If
  Ink = Ink + 1 + Skip
 Next i
 RceAnn = Annual

End Function

''''''''''**********************************

Sub Pce(Year)
 Dim PScale As Single
 Dim PValue As Single
 Dim PNumPay As Single
 Dim PPayYear As Single
 Dim PPer As Single
 Dim PInf As Single
 Dim Att As String

 Set DATASheet = ActiveWorkbook.Worksheets("DATA")
 Set Pce_Cells = DATASheet.Range("Y5:Y250")
 Inf = DATASheet.Range("F6")

 i = 4

 For Each cell In Pce_Cells

    If cell.Value = "" Then Exit Sub
     i = i + 1
     Att = cell.Value & "_DATA"
```

```
      x = ActiveWorkbook.Names(Att)
      Cat = cell.Offset(0, 1)
      Select Case Cat
           Case "Capital_Cost":
              Sheets("Costs").Cells(Year + 20, 6) = Sheets("Costs").Cells(Year + 20, 6) + _
PceAnn(Inf, Year,  ActiveWorkbook.Worksheets("DATA").Range(Att)) 'RValue, RStartYear, _
RNumpay, RSkip)

           Case "R&D_Cost":
              Sheets("Costs").Cells(Year + 20, 12) = Sheets("Costs").Cells(Year + 20, 12) + _
PceAnn(Inf, _ Year, ActiveWorkbook.Worksheets("DATA").Range(Att)) 'RValue, RStartYear,
_ RNumpay, RSkip)
           Case "Operations&Maintenance_Cost":
              Sheets("Costs").Cells(Year + 20, 9) = Sheets("Costs").Cells(Year + 20, 9) + _
PceAnn(Inf, _ Year, ActiveWorkbook.Worksheets("DATA").Range(Att)) 'RValue, RStartYear,
_  RNumpay, RSkip)
           Case "Phase_out_Cost":
              Sheets("Costs").Cells(Year + 20, 15) = Sheets("Costs").Cells(Year + 20, 15) + _
PceAnn(Inf, _ Year, ActiveWorkbook.Worksheets("DATA").Range(Att)) 'RValue, RStartYear, _
RNumpay, RSkip)
    End Select

 Next cell
End Sub

Function PceAnn(Inf, Year, List)

 ScFac = List(1)
 Value = List(2)
 Numpay = List(3)

 m = 4
 Annual = 0
 For i = 1 To Numpay
    If Year = List(m) Then
    Annual = Value * List(m + 1) * (1 + Inf) ^ Year
    Exit For
    End If
    m = m + 2
Next
PceAnn = Annual * ScFac
End Function

''''''''''***********************************
```

```
""" Net Present Value Calculations

Sub NPC(Year, IntRate)
   Set Sheet = ActiveWorkbook.Sheets("Costs")
   'Npc for Capital Cost
   For i = 0 To Year
     CapitalCost = CapitalCost + (Sheet.Cells(20 + i, 6)) * 1 / (1 + IntRate) ^ i
     OpCost = OpCost + (Sheet.Cells(20 + i, 9)) * 1 / (1 + IntRate) ^ i
     RDCost = RDCost + (Sheet.Cells(20 + i, 12)) * 1 / (1 + IntRate) ^ i
     Phcost = Phcost + (Sheet.Cells(20 + i, 15)) * 1 / (1 + IntRate) ^ i
   Next
     Sheet.Range("D10").Value = CapitalCost
     Sheet.Range("D11").Value = OpCost
     Sheet.Range("D12").Value = RDCost
     Sheet.Range("D13").Value = Phcost
     Sheet.Range("D7").Value = CapitalCost + OpCost + RSCost + Phcost

End Sub
" End of Calculation Module
"*****************************************************
"" Tis Module promts user to input cost elements according to
""associated WBS

   Public TCEi As Integer
   Public RCEi As Integer
   Public PCEi As Integer
   Public Tce_Cells As Range
   Public DATASheet As Worksheet

   Dim TypeOptCnt As Integer
   Dim CatOptCont As String
   Dim Cnt As String

Sub AssignNumbers()
   TCEi = 0
   RCEi = 0
   PCEi = 0
End Sub

"""" Range Definitions

 Sub GetCostElement()

 ' Declaration of object variables
```

```
  Dim Dialog As DialogSheet
  Dim EditName As DropDown
  Dim TCE_Opt As OptionButton
  Dim RCE_Opt As OptionButton
  Dim RD_Opt As OptionButton
  Dim Capital_Opt As OptionButton
  Dim OpsMan_Opt As OptionButton

' Declaration of loop control variable : # of Cost Elements

  Dim t As Integer

' Initialize the object variables

  Set Dialog = ThisWorkbook.DialogSheets("CostElements")
  Set EditName = Dialog.DropDowns("CEName")
  Set TCE_Opt = Dialog.OptionButtons("TCE")
  Set RCE_Opt = Dialog.OptionButtons("RCE")
  Set RD_Opt = Dialog.OptionButtons("RD")
  Set Capital_Opt = Dialog.OptionButtons("CAP")
  Set OpsMan_Opt = Dialog.OptionButtons("OM")


  InputCont = True

  Do While InputCont

    EditName.Text = ""
    InputCont = Dialog.Show

    If Not InputCont Then
      CopyLists
      Exit Sub
    End If
      TypeOptCnt = CostType(TCE_Opt.Value, RCE_Opt.Value)
      CatOptCont = CostCat(RD_Opt, Capital_Opt, OpsMan_Opt)


    Select Case TypeOptCnt
      Case 1: Call TCE_Input(EditName.Text, CatOptCont)
      Case 2: Call RCE_Input(EditName.Text, CatOptCont)
      Case 3: Call PCE_Input(EditName.Text, CatOptCont)
    End Select

  Loop
```

```
End Sub

Sub ExCont()
      Cnt = Application.Caller
End Sub


Function CostType(x, y)
      If x = xlon Then
         CostType = "1"
      ElseIf y = xlon Then
         CostType = "2"
      Else
         CostType = "3"
      End If

End Function

Function CostCat(x, y, z)

         If x = xlon Then
            CostCat = "R&D_Cost"
         ElseIf y = xlon Then
            CostCat = "Capital_Cost"
         ElseIf z = xlon Then
            CostCat = "Operations&Maintenance_Cost"
         Else
            CostCat = "Phase_out_Cost"
         End If
End Function



Sub TCE_Input(TCEName, TCECat)

   Dim Tce_Cells As Range

   Set DATASheet = ActiveWorkbook.Worksheets("DATA")
   Set Tce_Cells = DATASheet.Range("H5:H250")
   Set TEC_Dialog = ThisWorkbook.DialogSheets("TCE_Val")


   Row = 4

   TEC_Dialog.Labels("LabelName").Text = TCEName
```

```
  TEC_Dialog.Labels("LabelCat").Text = TCECat
  TEC_Dialog.EditBoxes("EditVal").Text = ""
  TEC_Dialog.EditBoxes("EditStartYear").Text = ""
  TEC_Dialog.EditBoxes("EditPhaseIn").Text = ""
  TEC_Dialog.EditBoxes("EditConstant").Text = ""
  TEC_Dialog.EditBoxes("EditPhaseOut").Text = ""
  TEC_Dialog.Show

  TCEValue = TEC_Dialog.EditBoxes("EditVal").Text

  For Each cell In Tce_Cells
  Row = Row + 1
  TceCellName = TCEName & "_DATA"
  Names.Add TceCellName, "=DATA!$I$" & CStr(Row) & ":$O$" & CStr(Row)

      If cell.Value = "" Then
        cell.Offset(0, 1) = 1
        cell.Value = TCEName
        cell.Offset(0, 2).Name = TCEName
        cell.Offset(0, 2) = TCEValue
        cell.Offset(0, 3) = TEC_Dialog.EditBoxes("EditStartYear").Text
        cell.Offset(0, 4) = TEC_Dialog.EditBoxes("EditPhaseIn").Text
        cell.Offset(0, 5) = TEC_Dialog.EditBoxes("EditConstant").Text
        cell.Offset(0, 6) = TEC_Dialog.EditBoxes("EditPhaseOut").Text
        cell.Offset(0, 7) = TCECat
        Exit For
      End If

  Next

End Sub

Sub RCE_Input(RCEName, RCECat)

  Dim Rce_Cells As Range


  Set Rce_Cells = ActiveWorkbook.Worksheets("DATA").Range("Q5:Q250")
  Set Rce_Dialog = ThisWorkbook.DialogSheets("RCE_Val")


  Row = 4
  Rce_Dialog.Labels("Labelname").Text = RCEName
  Rce_Dialog.Labels("LabelCat").Text = RCECat
  Rce_Dialog.EditBoxes("EditVal").Text = ""
```

```
  Rce_Dialog.EditBoxes("EditNum").Text = ""
  Rce_Dialog.EditBoxes("EditYear").Text = ""
  Rce_Dialog.EditBoxes("EditSkip").Text = ""
  Rce_Dialog.Show

  RCEValue = Rce_Dialog.EditBoxes("EditVal").Text

  For Each cell In Rce_Cells
  Row = Row + 1
  RceCellName = RCEName & "_Data"
  Names.Add RceCellName, "=DATA!$R$" & CStr(Row) & ":$W$" & CStr(Row)

      If cell.Value = "" Then
        cell.Offset(0, 1) = 1
        cell.Value = RCEName
        cell.Offset(0, 2).Name = RCEName
        cell.Offset(0, 2) = RCEValue
        cell.Offset(0, 3) = Rce_Dialog.EditBoxes("EditYear").Text
        cell.Offset(0, 4) = Rce_Dialog.EditBoxes("EditNum").Text
        cell.Offset(0, 5) = Rce_Dialog.EditBoxes("EditSkip").Text
        cell.Offset(0, 6) = RCECat
        Exit For
      End If

  Next


End Sub

Sub PCE_Input(PCEName, PCECat)
  Dim DATASheet As Worksheet
  Dim Pce_Dilaog As DialogSheet
  Dim Pce_PayDialog As DialogSheet
  Dim Pce_Cells As Range
  Dim Row As Integer
  Dim percent As Single

  Set DATASheet = ActiveWorkbook.Worksheets("DATA")
  Set Pce_Cells = DATASheet.Range("Y5:Y250")
  Set Pce_Dialog = ThisWorkbook.DialogSheets("PCE_Val")
  Set Pce_PayDialog = ThisWorkbook.DialogSheets("PCE_Pay")

  Pce_Dialog.Labels("Labelname").Text = PCEName
  Pce_Dialog.Labels("LabelCat").Text = PCECat
  Pce_Dialog.EditBoxes("EditVal").Text = ""
```

```
Pce_Dialog.EditBoxes("EditNum").Text = ""

Pce_Dialog.Show

PceValue = Pce_Dialog.EditBoxes("EditVal").Text
PceNumPay = Pce_Dialog.EditBoxes("EditNum").Text
Row = 4

  For Each cell In Pce_Cells
    Row = Row + 1
    If cell.Value = "" Then
      cell.Value = PCEName
      cell.Offset(0, 1) = PCECat
      cell.Offset(0, 2) = 1
      cell.Offset(0, 3).Name = PCEName
      cell.Offset(0, 3) = PceValue
      cell.Offset(0, 4) = PceNumPay
      PceCellName = PCEName & "_Data"
      Names.Add PceCellName, "=DATA!$AA" & CStr(Row) & ":$CA$" & CStr(Row)

Start:      percent = 0

      For i = 1 To 2 * PceNumPay Step 2

        Pce_PayDialog.Labels("PayNo").Text = CStr((i + 1) / 2)
        Pce_PayDialog.EditBoxes("EditYears").Text = ""
        Pce_PayDialog.EditBoxes("EditPer").Text = ""
        Pce_PayDialog.Show

        cell.Offset(0, 4 + i) = Pce_PayDialog.EditBoxes("EditYears").Text
        cell.Offset(0, 5 + i) = Pce_PayDialog.EditBoxes("EditPer").Text
        percent = percent + cell.Offset(0, 5 + i)

      Next

        If percent <> 1 Then
          conf = vbOKOnly + vbCritical
          Msg = "Sum of percentages must be one." & Chr(13)
          Msg = Msg & "Please enter years and percentages again. "
          Ans = MsgBox(Msg, conf)
          GoTo Start
        End If
      Exit For
    End If
Next
```

```
End Sub
`` End of Cost Element Input Module
**************************************************************************************
*

' Edit Module
' EditMod sub routine takes one attribute which may have one of two values 1 and 2. If x=1 _
EditModule  shows
' the prompts for new cost elements or variables. If x=2 EditMod prompts the user to change the
_ values of  existing
' variables and cost elements.
Dim VarCost As String
Sub EditMod(x)
   Dim EditNewMod As DialogSheet

   Set EditNewMod = ThisWorkbook.DialogSheets("NewMod")

   EditBoxOK = True

   Do While EditBoxOK

      EditBoxOK = ThisWorkbook.DialogSheets("Edit").Show

   If Not EditBoxOK Then

      Exit Sub
   End If
     Select Case VarCost
        Case "Var":
              Variableinput = x
              If x = 2 Then
                 EditNewMod.OptionButtons("OptionNew").Text = "Add New Variable"
                 EditNewMod.OptionButtons("OptionMod").Text = "Modify Existing Variable"
                 EditNewMod.OptionButtons("OptionDel").Text = "Delete Variable"
                 EditNewMod.Show
                 Variableinput = OptionCheck(EditNewMod.OptionButtons("OptionNew"), _
                  EditNewMod.OptionButtons("OptionMod"))

              End If

              Select Case Variableinput
                     Case "1": VarInputRout
                     Case "2": EditVar
                     Case "3": DelVar
                 End Select
```

```
        Case "Cost":
              CostElemInput = x
              If x = 2 Then
                 EditNewMod.OptionButtons("OptionNew").Text = "Add New Cost Element"
                 EditNewMod.OptionButtons("OptionMod").Text = "Modify Existing Cost
Element"
                 EditNewMod.OptionButtons("OptionDel").Text = "Delete Cost Element"
                 EditNewMod.Show
                 CostElemInput = OptionCheck(EditNewMod.OptionButtons("OptionNew"), _
                  EditNewMod.OptionButtons("OptionMod"))


              End If
              Select Case CostElemInput
                      Case "1": GetCostElement
                      Case "2": EditCostElements
                      Case "3": DelCostElement
              End Select

        Case "ScaleSet": ScaleCal
        Case "Distribution": EnterDistribution
        Case "Fore": Forecasts
      End Select

   Loop

End Sub

Sub Button()
   VarCost = Application.Caller
End Sub

''''*************************************************************************
******************
Sub EditVar()
     Set VarInDialog = ThisWorkbook.DialogSheets("VarInput")
     Set Sheet = ActiveWorkbook.Sheets("DATA")

TryAgain:
     ThisWorkbook.DialogSheets("ScaleVarDialog").Labels("Label").Text = " Choose the _
Variable to modify"
     ThisWorkbook.DialogSheets("ScaleVarDialog").Show
     VarName =
ThisWorkbook.DialogSheets("ScaleVarDialog").EditBoxes("EditScaleVar").Text
```

```
    If VarCost = "Cancel" Then Exit Sub
    If VarName = "" Then
       MsgBox "If you want to modify enter the name of  variable"
       GoTo TryAgain
    End If
    If check(VarName) = 1 Then GoTo TryAgain

    VarInDialog.EditBoxes("VarEditName").Text = VarName

    VarInDialog.EditBoxes("VarEditVal").Text = _
Sheet.Range(ActiveWorkbook.Names(VarName).RefersTo).Value

    VarInDialog.Show

    If VarCost = "EditMenu" Then Exit Sub

    Sheet.Range(ActiveWorkbook.Names(VarName).RefersTo).Value = _
VarInDialog.EditBoxes("VarEditVal").Text
    VarName1 = VarInDialog.EditBoxes("VarEditName").Text
    Sheet.Range(ActiveWorkbook.Names(VarName).RefersTo).Name = _
VarInDialog.EditBoxes("VarEditName").Text

    If Not VarInDialog.EditBoxes("VarEditName").Text = VarName Then

        ActiveWorkbook.Names(VarName).Delete

    End If
    Sheet.Range(ActiveWorkbook.Names(VarName1).RefersTo).Offset(0, -1) = _
VarInDialog.EditBoxes("VarEditName").Text

    CopyLists

End Sub
''''''**********************************************************************
***********************
Sub DelVar()

TryAgain:
    ThisWorkbook.DialogSheets("ScaleVarDialog").Labels("Label").Text = "Choose the _
 variable that you  want to " & Chr(13) & "Delete"
    ThisWorkbook.DialogSheets("ScaleVarDialog").Show
    VarName =
ThisWorkbook.DialogSheets("ScaleVarDialog").EditBoxes("EditScaleVar").Text
    If VarCost = "Cancel" Then Exit Sub
    If VarName = "" Then
```

```
        MsgBox "If you want to delete enter the name of  variable"
        GoTo TryAgain
    End If
    If check(VarName) = 1 Then GoTo TryAgain

    ActiveWorkbook.Worksheets("DATA").Range(VarName).Offset(0, 1).Delete
    ActiveWorkbook.Worksheets("DATA").Range(VarName).Delete
    ActiveWorkbook.Names(VarName).Delete
    CopyLists

End Sub
'''''**********************************************************************
***********************
Sub DelCostElement()

TryAgain:
    ThisWorkbook.DialogSheets("ScalingCElements").Labels("labelCost").Text = _
    "Choose the Cost elements you want to delete"
    ThisWorkbook.DialogSheets("ScalingCElements").Show
    ElementName = _
ThisWorkbook.DialogSheets("ScalingCElements").EditBoxes("EditName").Text
    If VarCost = "Cancel" Then Exit Sub
    If ElementName = "" Then
        MsgBox "If you want to modify enter the name of  variable"
        GoTo TryAgain
    End If
    If check(ElementName) = 1 Then GoTo TryAgain

    Select Case Elementtype(ElementName)
      Case "TCE":
              x = ActiveWorkbook.Sheets("DATA").Range(ElementName).Offset(0, _
-2).Address(xlA1)
              y = ActiveWorkbook.Sheets("DATA").Range(ElementName).Offset(0, _
5).Address(xlA1)
              ActiveWorkbook.Sheets("DATA").Range(x & ":" & y).Delete (xlUp)
              ActiveWorkbook.Names(ElementName).Delete (xlUp)

      Case "RCE":
              x = ActiveWorkbook.Sheets("DATA").Range(ElementName).Offset(0, _
-2).Address(xlA1)
              y = ActiveWorkbook.Sheets("DATA").Range(ElementName).Offset(0, _
4).Address(xlA1)
              ActiveWorkbook.Sheets("DATA").Range(x & ":" & y).Delete (xlUp)
              ActiveWorkbook.Names(ElementName).Delete (xlUp)
      Case "PCE":
```

```
                x = ActiveWorkbook.Sheets("DATA").Range(ElementName).Offset(0, _
-3).Address(xlA1)
                y = ActiveWorkbook.Sheets("DATA").Range(ElementName).Offset(0, _
51).Address(xlA1)
                ActiveWorkbook.Sheets("DATA").Range(x & ":" & y).Delete (xlUp)
                ActiveWorkbook.Names(ElementName).Delete (xlUp)
    End Select

    CopyLists

End Sub

''***************************************************************************
*****

Sub EditCostElements()
   'Dim CostDialog As DialogSheet

  ' Set CostDialog = ThisWorkbook.DialogSheets("CostElements")
   'Set sheet = ActiveWorkbook.Sheets("DATA")

TryAgain:
 ThisWorkbook.DialogSheets("ScalingCElements").Labels("labelCost").Text = "Choose the _
Cost   elements you want to modify"
   ThisWorkbook.DialogSheets("ScalingCElements").Show
   ElementName =
ThisWorkbook.DialogSheets("ScalingCElements").EditBoxes("EditName").Text
   If VarCost = "Cancel" Then Exit Sub
     If ElementName = "" Then
        MsgBox "If you want to modify enter the name of  variable"
        GoTo TryAgain
     End If
   If check(ElementName) = 1 Then GoTo TryAgain
   Select Case Elementtype(ElementName)
       Case "TCE": ModifTCE (ElementName)
       Case "RCE": ModifRCE (ElementName)
       Case "PCE": ModifPCE (ElementName)
  End Select

End Sub
'''*************************************************************
"" this Subroutine shows and modifies the Trapezoid cost Elements

Sub ModifTCE(y)
```

```
    Dim Tce_Cells As Range

    Set TCESheet = ActiveWorkbook.Worksheets("DATA")

    Set TCE_Dialog = ThisWorkbook.DialogSheets("TCE_Val")



    TCE_Dialog.Labels("LabelName").Text = y
    TCE_Dialog.Labels("LabelCat").Text = TCESheet.Range(y).Offset(0, 5).Value
    TCE_Dialog.EditBoxes("EditVal").Text = TCESheet.Range(y).Value
    TCE_Dialog.EditBoxes("EditStartYear").Text = TCESheet.Range(y).Offset(0, 1).Value
    TCE_Dialog.EditBoxes("EditPhaseIn").Text = TCESheet.Range(y).Offset(0, 2).Value
    TCE_Dialog.EditBoxes("EditConstant").Text = TCESheet.Range(y).Offset(0, 3).Value
    TCE_Dialog.EditBoxes("EditPhaseOut").Text = TCESheet.Range(y).Offset(0, 4).Value
    TCE_Dialog.Show

     TCESheet.Range(y).Name = e
     TCESheet.Range(y) = TCE_Dialog.EditBoxes("EditVal").Text
     TCESheet.Range(y).Offset(0, 1) = TCE_Dialog.EditBoxes("EditStartYear").Text
     TCESheet.Range(y).Offset(0, 2) = TCE_Dialog.EditBoxes("EditPhaseIn").Text
     TCESheet.Range(y).Offset(0, 3) = TCE_Dialog.EditBoxes("EditConstant").Text
     TCESheet.Range(y).Offset(0, 4) = TCE_Dialog.EditBoxes("EditPhaseOut").Text

End Sub
'**********************************************************************
Sub ModifRCE(y)
Dim RCESheet As Worksheet


   Set RCESheet = ActiveWorkbook.Worksheets("DATA")
   Set Rce_Dialog = ThisWorkbook.DialogSheets("RCE_Val")


   Rce_Dialog.Labels("Labelname").Text = y
   Rce_Dialog.Labels("LabelCat").Text = RCESheet.Range(y).Offset(0, 4)
   Rce_Dialog.EditBoxes("EditVal").Text = RCESheet.Range(y)
   Rce_Dialog.EditBoxes("EditNum").Text = RCESheet.Range(y).Offset(0, 1)
   Rce_Dialog.EditBoxes("EditYear").Text = RCESheet.Range(y).Offset(0, 2)
   Rce_Dialog.EditBoxes("EditSkip").Text = RCESheet.Range(y).Offset(0, 3)
   Rce_Dialog.Show


   RCESheet.Range(y) = Rce_Dialog.EditBoxes("EditVal").Text
   RCESheet.Range(y).Offset(0, 2) = Rce_Dialog.EditBoxes("EditYear").Text
```

```
   RCESheet.Range(y).Offset(0, 1) = Rce_Dialog.EditBoxes("EditNum").Text
   RCESheet.Range(y).Offset(0, 3) = Rce_Dialog.EditBoxes("EditSkip").Text

End Sub
'''*************************************************************
Sub ModifPCE(y)
   Dim PCEDATASheet As Worksheet
   Dim Pce_Dilaog As DialogSheet
   Dim Pce_PayDialog As DialogSheet
   Dim Pce_Cells As Range
   Dim Row As Integer
   Dim percent As Single

   Set PCEDATASheet = ActiveWorkbook.Worksheets("DATA")
  ' Set Pce_Cells = PCEDATASheet.Range("Y5:Y250")
   Set Pce_Dialog = ThisWorkbook.DialogSheets("PCE_Val")
   Set Pce_PayDialog = ThisWorkbook.DialogSheets("PCE_Pay")

   Pce_Dialog.Labels("Labelname").Text = y
   Pce_Dialog.Labels("LabelCat").Text = PCEDATASheet.Range(y).Offset(0, -1)
   Pce_Dialog.EditBoxes("EditVal").Text = PCEDATASheet.Range(y)
   Pce_Dialog.EditBoxes("EditNum").Text = PCEDATASheet.Range(y).Offset(0, 1)

   Pce_Dialog.Show

   PceValue = Pce_Dialog.EditBoxes("EditVal").Text
   PceNumPay = Pce_Dialog.EditBoxes("EditNum").Text


Start:      percent = 0

         For i = 1 To 2 * PceNumPay Step 2

            Pce_PayDialog.Labels("PayNo").Text = CStr((i + 1) / 2)
            Pce_PayDialog.EditBoxes("EditYears").Text = PCEDATASheet.Range(y).Offset(0,
_
 1 + i)
            Pce_PayDialog.EditBoxes("EditPer").Text = PCEDATASheet.Range(y).Offset(0, _
2 + i)
            Pce_PayDialog.Show

            PCEDATASheet.Range(y).Offset(0, 1 + i) = _
Pce_PayDialog.EditBoxes("EditYears").Text
            PCEDATASheet.Range(y).Offset(0, 2 + i) =
Pce_PayDialog.EditBoxes("EditPer").Text
```

```
            percent = percent + PCEDATASheet.Range(y).Offset(0, 2 + i)

        Next


            If percent <> 1 Then
                conf = vbOKOnly + vbCritical
                Msg = "Sum of percentages must be one." & Chr(13)
                Msg = Msg & "Please enter years and percentages again. "
                Ans = MsgBox(Msg, conf)
                GoTo Start
            End If
          x = PCEDATASheet.Range(y).Offset(0, 1 + i).Address(xlA1)
          y = PCEDATASheet.Range(y).Offset(0, 51 + i).Address(xlA1)

          PCEDATASheet.Range(x & ":" & y).Clear


End Sub
'***************************************************************
"" This Function returns the Type of cost Element (TCE,RCE,PCE)

Function Elementtype(y)
   x = ActiveWorkbook.Worksheets("DATA").Range(y).Address(ReferenceStyle:=xlA1)
   elementColumn = Left(x, 2)

  Select Case elementColumn
      Case "$J": Elementtype = "TCE"
      Case "$S": Elementtype = "RCE"
      Case "$A": Elementtype = "PCE"
 End Select

End Function

'****************************************************************
"" This functions checks for the existence of the given name of variable and cost element
""


Function check(Search)
     test = False
     For Each x In Names
        If x.Name = Search Then
            test = True
            Exit For
```

```
        End If
      Next
      Select Case test
          Case False:
            Call Namebox(Search)
            check = 1
          Case True: check = 2

      End Select
End Function

Sub Namebox(y)
        conf = vbOKOnly + vbCritical
        Msg = """" & y & """" & "  is not exist" & Chr(13)
        Msg = Msg & "Please check the name and enter again. "
        Ans = MsgBox(Msg, conf)
 End Sub
" End of Edit Module
""''**************************************************************************
********
"" Scale Module
"" This module contains the subroutines and functions which calculates the
"" scale factors and use them in cost sheet.

Public ScaleVar As Single
Public ScaleVarName As String
Dim ConButton As String
Dim Rows As Integer
Dim Ref As String

Sub Findref(y)
Set DataColum = y 'ActiveWorkbook.Worksheets("DATA").Range("H5:h250")
  i = 0
  For Each Item In DataColum

        If Item.Value = "" Then
          x = Item.Address
          Exit For
        End If
        i = i + 1
  Next Item
  Ref = DataColum(1).Address & ":" & x
  Rows = i + Rows
End Sub
Sub CopyLists()
```

```
  Set ListSheet = ThisWorkbook.Worksheets("ScaleData")
  ListSheet.Range("A4:A1000").Clear
  ListSheet.Range("D4:D1000").Clear

 Rows = 0
 ActiveWorkbook.Worksheets("DATA").Range("E5:E1005").Copy
ThisWorkbook.Worksheets("ScaleData").Paste
ThisWorkbook.Worksheets("ScaleData").Range("A4:A1004")

 Call Findref(ActiveWorkbook.Worksheets("DATA").Range("H5:h250"))
 ActiveWorkbook.Worksheets("DATA").Range(Ref).Copy
 ThisWorkbook.Worksheets("ScaleData").Paste
ThisWorkbook.Worksheets("ScaleData").Range("D4:D" & CStr(4 + Rows))
 NewRow = Rows + 4

 Call Findref(ActiveWorkbook.Worksheets("DATA").Range("Q5:Q250"))
 ActiveWorkbook.Worksheets("DATA").Range(Ref).Copy
 ThisWorkbook.Worksheets("ScaleData").Paste
ThisWorkbook.Worksheets("ScaleData").Range("D" & CStr(NewRow) & ":D" _
  & CStr(4 + Rows))

 NewRow = Rows + 4
 Call Findref(ActiveWorkbook.Worksheets("DATA").Range("Y5:Y250"))
 ActiveWorkbook.Worksheets("DATA").Range(Ref).Copy
 ThisWorkbook.Worksheets("ScaleData").Paste
ThisWorkbook.Worksheets("ScaleData").Range("D" & CStr(NewRow) & ":D" _
 & CStr(4 + Rows))

End Sub

Sub ScaleCal()

 Dim ScaleSheet As DialogSheet
 Dim ScaleVarSheet As DialogSheet


 Set ScaleSheet = ThisWorkbook.DialogSheets("Scale")
 Set ScaleVarSheet = ThisWorkbook.DialogSheets("ScaleVarDialog")




 ScaleVarSheet.Labels("Label").Text = "Choose the variable that you want to " & Chr(13) _
 & "scale the  model on"
 ConButton = ""
```

```
  ScaleVarSheet.EditBoxes("EditScaleVar").Text = ""
  ScaleVarSheet.Show
  If ConButton = "Cancel" Then RunMainMenu

  ScaleVarName = ScaleVarSheet.EditBoxes("EditScaleVar").Text
  MsgBox ScaleVarName
  ThisWorkbook.Sheets("ScaleData").Range("B12").Value = _
ActiveWorkbook.Names(ScaleVarName).Value
  ThisWorkbook.Sheets("ScaleData").Range("B12").Clear

  ConButton = ""
  ScaleSheet.Show
  Scaleway = OptionCheck(ScaleSheet.OptionButtons("SingleScale"), _
ScaleSheet.OptionButtons("MultiScale"))

  If ConButton = "Cancel" Then RunMainMenu

  Select Case Scaleway
     Case "1": SingleScale  ' Calls the associated sub to perform scaling according to
     Case "2": MultiScale   ' the selection on the left
     Case "3": NoScale      ' Resets all scaling factors to 1.
 End Select

End Sub
''''''''*********************************************************************
Sub CheckScaleButton()
   ConButton = Application.Caller
   Call Button
End Sub
''''''''*********************************************************************
Sub NoScale()
   ThisWorkbook.Worksheets("Costs").Range("E15").Value = "No Scaling"
   ActiveWorkbook.Sheets("Costs").Range("E7") = 1
   ResetFactors
End Sub
'''''''**************************************************************************
*
Sub SingleScale()

  ResetFactors  ' Resets the scaling factors of the multiable scaling
  ThisWorkbook.Worksheets("Costs").Range("E15").Value = "Single Factor Scaling"
  Call ScaleFactor(ActiveWorkbook.Sheets("Costs").Range("E7"), ScaleVarName)
  RunMainMenu
End Sub
''''''''''''''**********************************
```

```
Sub MultiScale()
   Dim MultiDialog As DialogSheet
   Dim EditCostName As EditBox

   Set MultiDialog = ThisWorkbook.DialogSheets("ScalingCElements")
   Set EditCostName = MultiDialog.EditBoxes("EditName")

   ThisWorkbook.Worksheets("Costs").Range("E15").Value = "Multi Factor Scaling "
   ActiveWorkbook.Sheets("Costs").Range("E7") = 1
   boxCont = True

   Do While boxCont
   i = 0
   ConButton = ""
   MultiDialog.Labels("labelCost").Text = "Choose the Cost elements that are scaled by " & _
Chr(13) &"the scaling variable"
   boxCont = MultiDialog.Show

     If ConButton = "Cancel" Then RunMainMenu
     If Not boxCont Then Exit Sub

     Call ScaleFactor(ActiveWorkbook.Worksheets("DATA").Range(EditCostName.Text).Offset(
_ 0 ,  -1), ScaleVarName)

     Loop

End Sub
''''''''''''''***********************************

''''''*************************************************************************
*
Sub ScaleFactor(FactorRange As Range, UnknownCap As String)
  Dim x As String
  Set Dialog = ThisWorkbook.DialogSheets("Factortype")
  Dialog.Show

  Cont = FactorType(Dialog.OptionButtons("LinearOpt"), Dialog.OptionButtons("ExpoOpt"))
  If ConButton = "Cancel" Then Exit Sub
  Select Case Cont
       Case "1": FactorRange.Formula = "=LinFac(" & ScaleVar & "," & UnknownCap & "," & _
        CStr(InputBox("Enter constant scaling factor.")) & ")"
       Case "2": FactorRange.Formula = "=ExpFac(" & ScaleVar & "," & UnknownCap & " ," &
_
        CStr(InputBox("Enter Exponential factor")) & ")"
```

```
        Case "3": FactorRange.Formula = BestFac
    End Select
End Sub
''''''''''''''''*****************************************
Function FactorType(x, y)
 If x = xlon Then
   FactorType = "1"
 ElseIf y = xlon Then
   FactorType = "2"
 Else
   FactorType = "3"
 End If
End Function




''''''''''''''''''''''**************
Function OptionCheck(x, y)
      If x = xlon Then
          OptionCheck = "1"
      ElseIf y = xlon Then
          OptionCheck = "2"
      ElseIf y = xloff And x = xloff Then
          OptionCheck = "3"
      End If

End Function
''''''''''''************************************
"" Scale functions
"""" This Function returns the Linear Scaling factor
Function LinFac(CapKnown, CapUn, Alfa)

     LinFac = Alfa * (CapUn / CapKnown)

End Function
""""*************************
' Returns the Exponential Scaling Factor

Function ExpFac(CapKnown, CapUn, Beta)

  ExpFac = (CapUn / CapKnown) ^ Beta

End Function
""""******************************
```

```
'''' Returns the Best-Fit Equation Scaling factor.
Function BestFac()

  Dim ScaleSheet As DialogSheet
  Dim ScaleVarSheet As DialogSheet
  Dim Formula As String

  Set ScaleSheet = ThisWorkbook.DialogSheets("Scale")
  Set ScaleVarSheet = ThisWorkbook.DialogSheets("ScaleVarDialog")

  ScaleVarSheet.Labels("Label").Text = "Please enter the Best-Fit Equation"
  ScaleVarSheet.Show

  Formula = ScaleVarSheet.EditBoxes("EditScaleVar").Text
  ThisWorkbook.Worksheets("ScaleData").Range("B12") = "=" & Formula
  Constant = ThisWorkbook.Worksheets("ScaleData").Range("B12")
  ThisWorkbook.Worksheets("ScaleData").Range("B12").Clear
  BestFac = "=(" & Formula & ")/" & CStr(Constant)

End Function


''''''''****************************************

Sub ScalingFactor(FactorRange As Range, UnknownCap As String)
  Dim x As String
  Set Dialog = ThisWorkbook.DialogSheets("Factortype")
  Dialog.Show

  Cont = FactorType(Dialog.OptionButtons("LinearOpt"), Dialog.OptionButtons("ExpoOpt"))
  If ConButton = "Cancel" Then Exit Sub
  'K = 6 ' CStr(KCap)
' Worksheets("sheet1").Cells(10, 10) = K
  Select Case Cont
      Case "1": FactorRange.Formula = "=LinFac(" & ScaleVar & "," & UnknownCap & "," & _
      CStr(InputBox("Enter constant scaling factor.")) & ")"
      Case "2": FactorRange.Formula = "=ExpFac(" & ScaleVar & "," & UnknownCap & "," &
_
      CStr(InputBox(" Enter Exponential factor")) & ")"
      Case "3": FactorRange.Formula = BestFac
  End Select
End Sub

Sub ResetFactors()
  Dim Cells As Range
```

```
   Dim Arr As Variant
   Set DSheet = ActiveWorkbook.Worksheets("DATA")

   Arr = Array("I", "R", "AA")

   For i = 0 To 2

      Set Cells = DSheet.Range(Arr(i) & "5:" & Arr(i) & "250")

      For Each cell In Cells
            If cell.Value = "" Then Exit For
            cell.Value = 1
      Next cell
   Next
End Sub
" *****End of Scale Module
'''*************************************************

"" Distribution Module
"" This Module allows user to define distributions and forecats

Sub EnterDistribution()
  Dim DisDialog As DialogSheet
  Dim RandDialog As DialogSheet

  Set RandDialog = ThisWorkbook.DialogSheets("RanVar")
  Set DisDialog = ThisWorkbook.DialogSheets("Distribution")
  RandDialog.Show
  If RandDialog.OptionButtons("OptVar") = xlon Then

  DisDialog.ListBoxes("ListBox").ListFillRange = "=ScaleData!$A$4:$A$1500"

  Else

  DisDialog.ListBoxes("ListBox").ListFillRange = "=ScaleData!$D$4:$D$1500"

  End If



Again:
  DisDialog.EditBoxes("EditRV").Text = ""
  varcont = DisDialog.Show
  x = DisDialog.EditBoxes("EditRV").Text
  If Not varcont Then Exit Sub
```

```
  If x = "" Then
   DisBox ("You must chose one Random Variable.")
   GoTo Again
  End If
  y = ActiveWorkbook.Names(x).RefersTo
  ActiveWorkbook.Worksheets("DATA").Activate
  Range(y).Select
  Application.Run Macro:="CB.DefineAssum"
  GoTo Again


End Sub

Sub DisBox(y)
      conf = vbOKOnly + vbCritical
      Msg = y & Chr(13)
      Msg = Msg & "Please enter again"
      Ans = MsgBox(Msg, conf)
 End Sub

Sub Forecasts()
 Dim Dialog As DialogSheet
 Dim EditFore As EditBox

 Set Dialog = ThisWorkbook.DialogSheets("Forecast")
 Set EditFore = Dialog.EditBoxes("EditFore")

Again:
 Forecont = Dialog.Show
 x = EditFore.Text

 If Not Forecont Then Exit Sub
 If x = "" Then
   DisBox ("You must chose Forecast")
   GoTo Again
 End If
 y = ActiveWorkbook.Names(x).RefersTo
 ActiveWorkbook.Worksheets("Costs").Activate
 Range(ActiveWorkbook.Names(x).RefersTo).Select

 Application.Run Macro:="CB.DefineFore"
 GoTo Again

End Sub
"****** End of Distribution Module
```

****

Appendix C: Life Cycle Cost Program User Manual

1. Minimum System Requirements

- Windows 95
- Excel 7
- Crystal Ball 4.0

2. Installation

Copy LCC add in file to Excel\Library directory. After starting Excel activate LCC from the "Add-In" function.

Install Crystal Ball on the hard drive according to Crystal Ball user Manual. When installing Crystal Ball do not choose automatic start option.

Activate Crystal Ball using Tools, "Add-In" function of Excel

Copy LCCMode.temp to Excel templates directory

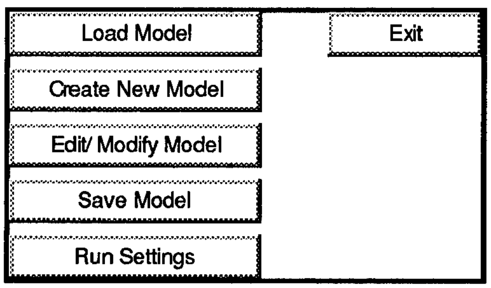
3. Running the Program.

Open new LCC Model from the File/ New/LCCModel.temp if new LCC is to be developed. If there is already developed model, open the xls file of the model.

There should be three sheets in the model, Main, Cost and Data. Click the "Main Menu" button in the "Main" sheet.

NOTE : IF AN ERROR ARISES CHECK THE NAME OF THE MACRO ASSIGNED TO BUTTON BY RIGHT MOUSE BUTTON CLICK- ASSIGN MACRO. THE NAME OF THE MACRO SHOULD BE " RUNMAINMENU. SINCE THIS MACRO IS DEFINED IN ADD-IN FILE DO NOT DESCRIBE THE PATH OF XLA FILE.

Main menu has SIX selections.



Main Menu Options

1. <u>*Load Model*</u>: When an Existing model is opened the first thing is to load the model to the program. This button copies the defined variable and cost element names to the program lists to reach the names easily during the interactions.

   AFTER CREATING NEW MODEL OR UPDATING THE EXISTING ONE, THE MODEL SHOULD BE LOAD AGAIN.

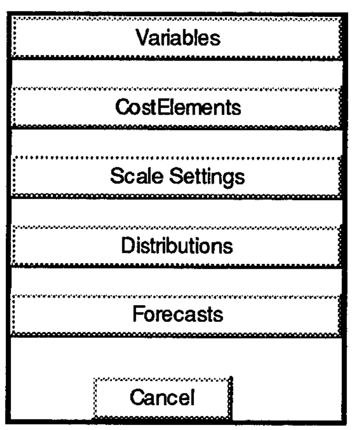
2. <u>*Create New Model:*</u> Starts the menu driven steps to define variables, cost elements, distributions and forecasts.

3. <u>*Edit/Modify Model:*</u> Starts the steps to modify existing model. User can change names and values of variables, values and parameters of cost elements.

NOTE: NAME AND CATEGORY OF A COST ELEMENT CANNOT BE CHANGED. THE COST ELEMENT SHOULD BE DELETED AND DEFINED AGAIN IF NAME OR CATEGORY OF THE COST ELEMENT IS TO BE UPDATED.

4. *Save Model:* Saves the model. Another way to save the model is to close Main Menu and use the Excel menu.
5. *Run Settings:* Opens the Run Menu which has selections for deterministic calculation of NPC, simulation settings and run simulation. IN THE SIMULATION SETTINGS WINDOWS UNDER THE MACRO OPTION IN THE ITERATION SEQUENCE AFTER RECALCULATION OF SPREAD SHEET THE MACRO "CALCULATE" SHOULD BE WRITTEN TO CALCULATE NPC IN EACH ITERATION.

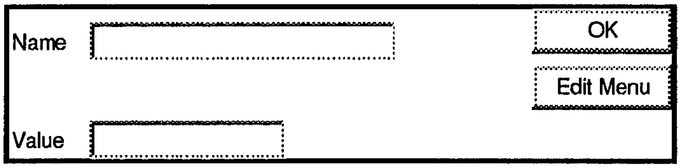
EDIT MENU OPTIONS



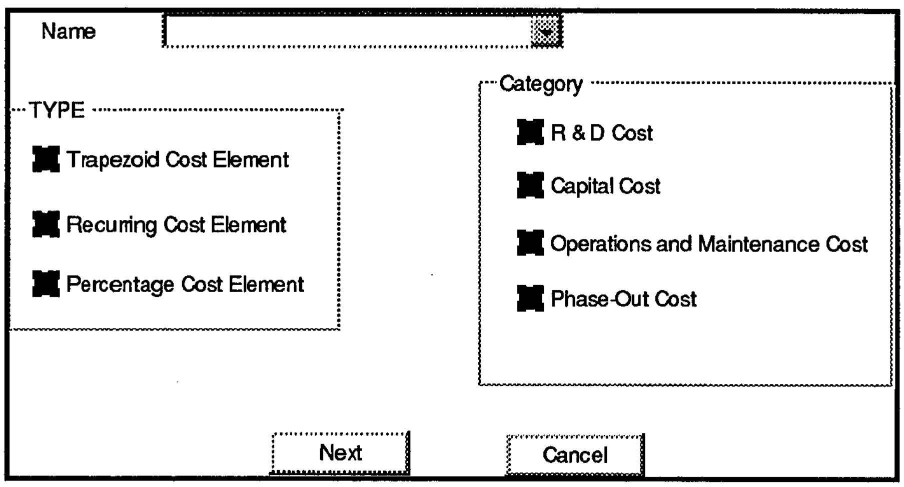
By using the Edit Menu the desired part of the model can be modified or created.

Variable Input Menu

When "Variables" is selected the following window appears. The name of the variable should not include any space. The variable value can be a constant, a distribution or a function of other variables. To assign a distribution to the variable, first a value is entered then after defining the variable, Distributions selection in Edit menu is used. Sixteen theoretical distributions are built in to Crystal Ball or a custom distribution can be built.



Cost Element Input Menu

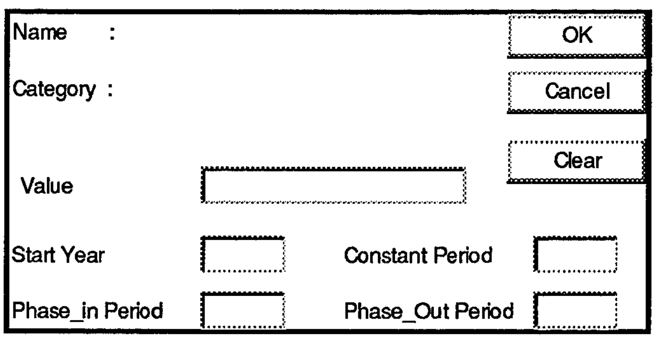


Cost elements can be defined using the Cost Element Input Menu. In the menu there are three types of information; Name, Type and Category of cost element. Name of the Cost element can be entered by the user or can be selected from the WBS which is placed to drop down list. An appropriate time phasing method can be chosen from three available cost element types. Cost element categories are also provided to keep track of different cost categories. NAME

SHOULD BE ENTERED FOR THE COST ELEMENT OR IT WILL CAUSE ERRORS IN THE FOLLOWING STEPS.

According to the type selections above, one of the following windows appears. The window name and category of the cost element are automatically displayed. User should enter the parameters.

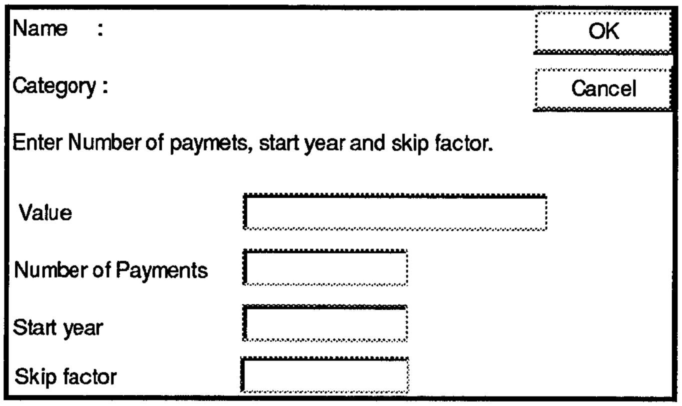
Trapezoid Cost Element



<u>*Value:*</u> Value refers to constant payment value of the trapezoid cost element. Value can be defined as constant, distribution or function of the variables defined. If the value is random variable and needs a distribution, any constant value should be defined and after finishing entering cost elements by using the Distributions window the value should be defined as one of the sixteen theoretical distribution or as an custom distribution. If the value is a function of variables first "=" should be entered to model. Excel built-in functions can be used.

Any of four parameters can also be defined as random variable or function of a variable as well as constant value.

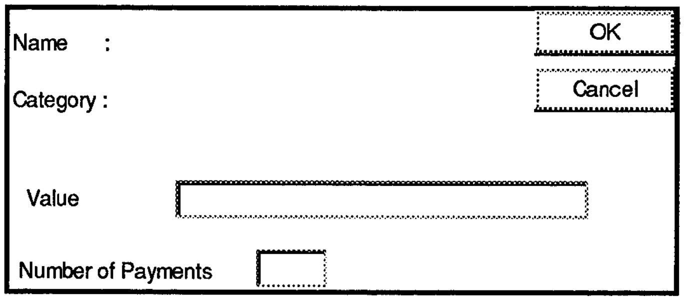
Recurring Cost Element



Value: Value refers to annual payments for the cost element. Value can be defined as constant, distribution or function of the variables defined. If the value is random variable and needs a distribution, any constant value should be defined and after finishing entering cost elements by using the Distributions window the value should be defined as one of the sixteen theoretical distribution or as an custom distribution. If the value is a function of variables first "=" should be entered to model. Excel built-in functions can be used.

Any of four parameters can also be defined as random variable or function of a variable as well as constant value.

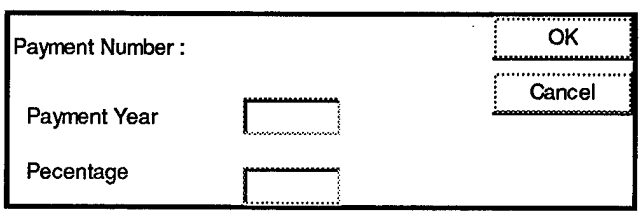
Percentage Cost Element



Percentage cost element window has two parameters to input. The first one is the value which refers to total value to be paid. The second is the number of payments.

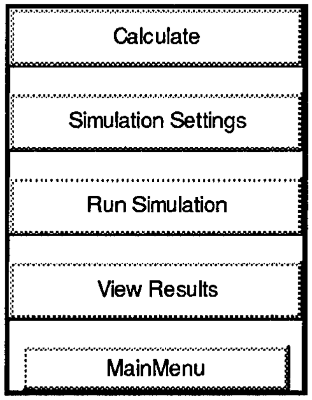
Value can be defined as constant, distribution or function of the variables defined. If the value is random variable and needs a distribution, any constant value should be defined and after finishing entering cost elements by using the Distributions window the value should be defined as one of the sixteen theoretical distribution or as an custom distribution. If the value is a function of variables first "=" should be entered to model. Excel built-in functions can be used.

Number of Payments should be an integer number. Only constant numbers can be assigned to this parameter. After entering the parameters, the following window repeats until the Number of Payments reached.



Payment number is displayed automatically. Payment year and Percentage that is paid in that year should be entered. Both of the parameters must be constant.

RUN MENU



Run Menu is displayed when Run Settings from the Main Menu is selected. It has five selections.

Calculate: Deterministically calculates the NPC of the introduced model. The selection is same as one iteration of the Monte Carlo simulation.

Simulation Setting: Runs the Crystal Ball windows which prompt to specify the simulation settings. Reference: Crystal Ball 4.0 user manual.

Run Simulation: Runs the simulation according to the settings.

View Results: Displays the result of calculations in the "Cost" sheet.

Main Menu: Returns to Main Menu.

Scaling

Before entering scaling settings, the cost should be calculated by using "Calculate" selection in Run Menu. Then scaling parameters can be entered through the Edit Menu. The steps showed below is followed.

1. Select the scaling variable from the provided list.
2. Select the scaling type,

Single factor scaling: Scaling is only applied to NPC. There is one factor and cost is escalated.

Multi-Factor Scaling: Scaling is accomplished in the level of cost elements.

3. If single factor scaling is selected then only one time one of the three scaling factors should be selected.
4. If Multi-Factor scaling is selected for each cost element desired to be scaled the selection from three methods should be repeated.

Scaling Method

Linear Scaling: For linear scaling, the slope parameter should be entered. The program prompts the user to enter the slope parameter.

$$C_x = C_k * n.\left(\frac{E_x}{E_k}\right)$$

Where,

C_x = Cost of plant and/or equipment item of size E_x

C_k = Known cost of plant and/or equipment item of size E_k

n = Slope parameter

Exponential Scaling: The program prompts the user to enter exponent "n" in the following formula. The scaled value of the cost element is the calculated depending on the value of scaling value.

$$C_x = C_k\left(\frac{E_x}{E_k}\right)^n$$

Where,

C_x = Cost of plant and/or equipment item of size E_x

C_k = Known cost of plant and/or equipment item of size E_k

n = Cost capacity exponent.

Best-Fit Equation Scaling: This method takes the ratio of the two cases of given best fit equation. The following equation shows the method. User is prompt to enter a regression model that explains the relation between scaling variable and cost element.

$$Cost_B = Cost_A x \frac{f(E_B)}{f(E_A)}$$

where

$f(E_B)$ = Predicted cost for capacity E_B.

$f(E_A)$ = Predicted cost for capacity E_A.

$Cost_A$ = Actual cost of capacity E_A

$Cost_B$ = Estimated cost of capacity E_B

Appendix D: Train Data

TRAIN#1

Dynamic Underground Stripping & 2 Phase Extraction

InterestRate	0.027
InflationRate	0
Performance	90
DnaplVolume	28037.8795995864
DnaplVolumeAq	=DnaplVolume-DnaplVolumeUpper
DnaplVolumeUpper	8470
PorosityAq	=0.09
VolumePerINjector	6000
SaturationAq	0.3
SoilVolAq	=DnaplVolumeAq/PorosityAq/SaturationAq/7.48051
HoursYear	520
Wage	75
Electricity	20000
Modifier	0.5
FlowRate	1000
ConsFlowRate	=IF(FlowRate<50,50,IF(FlowRate>1000,1000,FlowRate))
OperatingEff	0.85
UnitPrice	=MIN(GAC,CatOx)
OperationalTime	=OperatingEff*365*24*60
Consentration	=1000000*DnaplVolume*Performance/100/(FlowRate*OperationalTime*OperatingTime*7.48051)
ConsConsentration	=IF(Consentration<50,50,IF(Consentration>10000,10000,Consentration))
DnaplDensity	1.46
DnaplMassAq	=DnaplVolumeAq*DnaplDensity*8.33717
DnaplMassUpper	=DnaplVolumeUpper*DnaplDensity*8.33717
CapitalUnitCost	12.44
OpsUnitCost	10
GAS	=10^(-0.23137*LOG(ConsConsentration) +0.000251*ConsFlowRate + 1.440329)
CatOx	=10^(-1.000371*LOG(ConsConsentration)-0.00153*ConsFlowRate +3.789181)
OperatingTime	=(1.731046*LN(100/(100-Performance)))/12
AreaAq	=SoilVolAq/30

AreaSat	2500
DnaplMass	=DnaplVolume*DnaplDensity*8.33717
DnaplMassTreated	=F36*Performance/100
SoilVolTreated	=(MAX(AreaAq,AreaSat)/9)*82/3
AnnualOffGass	=IF(OperatingTime>1, DnaplMassTreated/OperatingTime*UnitPrice,DnaplMassTreated*UnitPrice)
CostFactor	=((1+InterestRate)^OperatingTime-1)/(InterestRate*(1+InterestRate)^OperatingTime)

TRAIN#2

2 Phase Extraction & Chemical Oxidation

InterestRate	0.027
InflationRate	0
Performance	90
DnaplVolume	499218.888114775
DnaplVolumeAq	=DnaplVolume-DnaplVolumeUpper
DnaplVolumeUpper	=8182+288
PorosityAq	=0.09
VolumePerINjector	6000
SaturationAq	0.3
GrainSize	3
SoilVolAq	=DnaplVolumeAq/PorosityAq/SaturationAq/7.48051
HoursYear	520
Wage	75
Electricity	20000
Modifier	0.5
FlowRate	120
ConsFlowRate	=IF(FlowRate<50,50,IF(FlowRate>1000,1000,FlowRate))
OperatingEff	0.85
ChemOpEff	0.85
InjectorRate	2
InjectorWells	=ROUNDUP(SoilVolChem/VolumePerINjector,0)
Injectorcon	=0.1
UnitPrice	=10^(-0.23137*LOG(ConsConsentration)+0.000251*ConsFlowRat

	e+1.440329)
OperationalTime	=OperatingEff*365*24*60
Consentration	=1000000*DnaplVolumeUpper/(FlowRate*OperationalTime*Time*7.48051)
ConsConsentration	=IF(Consentration<50,50,IF(Consentration>10000,10000,Consentration))
DaysToOps	=ROUNDUP(18.26926*LN(100/(100-Performance))+InjectorWells/InjectorRate,0)
DnaplDensity	1.46
DrumHydPer	=ROUNDUP(DnaplVolumeAq*DnaplDensity*8.33717*6.5/500,-2)
DayOnSite	=ROUNDUP(DrumHydPer/DrumRate,0)
DrumRate	=InjectorRate*InjectorWells*Injectorcon*ChemOpEff*ChOperatingTime*60/55
ChoperatingTime	8
DnaplMassAq	=DnaplVolumeAq*DnaplDensity*8.33717
DnaplMassUpper	=DnaplVolumeUpper*DnaplDensity*8.33717
TotalTime	=(DaysToOps+DayOnSite)/365

TRAIN #3
6 PHASE & CHEMICAL OXIDATION

InterestRate	0.027
InflationRate	0
Performance	99.99
DnaplVolume	170000
DnaplVolumeAq	=DnaplVolume-DnaplVolumeSat-DnaplVolumeVad
DnaplVolumeSat	8182
DnaplVolumeVad	288
DnaplDensity	=1.46
DnaplMassAq	=DnaplVolumeAq*DnaplDensity*8.33717
DnaplMassVad	=DnaplVolumeVad*DnaplDensity*8.33717
DnaplMassSat	=DnaplVolumeSat*DnaplDensity*8.33717
SoilVolumeAq	=DnaplVolumeAq/PorosityAq/SaturationAq/7.48051

SoilVolumeVad	=DnaplVolumeVad/PorosityVad/SaturationVad/7.48051
SoilVolumeSat	=DnaplVolumeSat/PorositySat/SaturationSat/7.48051
PorosityAq	0.09
PorosityVad	0.35
PorositySat	0.25
SaturationAq	0.3
SaturationVad	0.18
SaturationSat	0.07
FlowRate	500
Consentration	=1000000*(DnaplVolumeVad+DnaplVolumeSat)/(FlowRate*OperationalTime*Time*7.48051)
ConsFlowRate	=IF(FlowRate<50,50,IF(FlowRate>10000,10000,FlowRate))
ConsConsentration	=IF(Consentration<50,50,IF(Consentration>10000,10000,Consentration))
CatOx	=10^(-1.000371*LOG(ConsConsentration)+-0.00153*ConsFlowRate+3.789181)
GAC	=10^(-0.23137*LOG(ConsConsentration)+0.000251*(ConsFlowRate)+1.440329)
UnitCost	=MIN(CatOx,GAC)
SPOperationEff	0.85
ArrayDiam	40
ArrayInfArea	=PI()*(ArrayDiam/2)^2
ContaminatedArea	=SoilVolumeSat/27
NumArrays	=ROUNDUP(ContaminatedArea/ArrayInfArea,0)
DepthTreatedZone	52
ArrayMaterialCost	6000
LaborCost	10000
DepthOver20	=DepthTreatedZone-20
ElectrodCost	60
AddArrayCost	=DepthOver20*ElectrodCost*6
TemWellsIns	20
TemWellCost	=TemWellsIns*DepthTreatedZone
TemWells	2
ElectricalCost	0.05
VadoseEnergy	90
VadoseEnergyCost	=VadoseEnergy*ElectricalCost
AnnualVadEnergyCost	=VadoseEnergyCost*SoilVolumeVad/27*1.1
OperationalEff	0.85
OperationalTime	=OperationalEff*365*24*60
SaturatedEnergy	180

SaturatedEnergy Cost	=SaturatedEnergy*ElectricalCost
AnnualSatEnergy Cost	=SaturatedEnergyCost*SoilVolumeSat/27
ArrayTransformer	4
Transformer	=ROUNDUP(NumArrays/ArrayTransformer,0)*300000
Instrument	35000
Condenser	25000
Stripper	15000
AmortizedCost	=Stripper+Condenser+Instrument +Transformer
AnnualAmortized Cost	=(InterestRate*(1+InterestRate)^5)/((1+InterestRate)^5-1)*AmortizedCost
GrainSize	3
ChVolumePreinjector	6000
ChDaysToOps	=ROUNDUP(18.26926*LN(100/(100-Performance))+ChInjectorWells/ChInjectorRate,0)
ChDayOnSite	=ROUNDUP(ChDrumHydPer/ChDrumRate,0)
ChDrumRate	=ROUNDUP(ChInjectorRate*ChInjectorWells*ChInjectorCon*ChOpsEff*ChOperatingTime*60/55,0)
ChDrumHydPer	=ROUNDUP(DnaplVolumeAq*DnaplDensity*8.33717*6.5/500,-2)
ChInjectorRate	2
ChInjectorWells	=ROUNDUP(SoilVolumeAq/ChVolumePerinjector,0)
ChInjectorCon	0.1
ChOpsEff	0.85
ChOperatingTime	8
AnnualMaintenance	=(DesignCost+Mobilization+DEMOBILIZATION+Closure+Arraycost+Lease)*0.1/Time
AnnualOffGasCost	=IF(Time>1,(DnaplMassSat+DnaplMassVad)*Performance/100/Time*UnitCost,(DnaplMassSat+DnaplMassVad)*Performance/100*UnitCost)
AnnualEnergyCost	=(AnnualSatEnergyCost+AnnualVadEnergyCost)*52/6
TotalTime	=(ChDaysToOps+ChDayOnSite)/365

Appendix E: Validation Data

The data to developed from MSE model to validate out model is presented in this appendix.

	Performance Level (%)	50 K Gallons	100 K Gallons	500 K Gallons
DUS	99.99	$ 2,499,688	$ 4,985,526	$ 13,643,409
	90	$ 2,370,080	$ 3,268,008	$ 7,214,114
	80	$ 2,089,066	$ 2,588,349	$ 6,656,938
	70	$ 1,681,938	$ 2,191,216	$ 6,341,160
	60	$ 1,392,852	$ 1,909,949	$ 6,122,594
	50	$ 1,168,530	$ 1,692,045	$ 5,956,626
2Phase & Oxidation	99.99	$ 6,054,481	$ 8,585,349	$ 29,033,961
	90	$ 4,190,214	$ 6,507,638	$ 25,130,842
	80	$ 3,667,841	$ 5,151 024	$ 22,487,711
	70	$ 3,221,600	$ 5,069,824	$ 19,919,161
	60	$ 2,807,207	$ 4,419,994	$ 17,378,149
	50	$ 2,410,366	$ 3,787,434	$ 14,852,137
6 Phase & Oxidation	99.99	$ 4,396,571	$ 6,927,439	$ 27,376,051
	90	$ 3,708,662	$ 6,025,735	$ 24,648,939
	80	$ 3,320,738	$ 5,403,921	$ 22,140,607
	70	$ 2,945,165	$ 4,793,389	$ 19,642,001
	60	$ 2,574,532	$ 4,187,319	$ 17,145,474
	50	$ 2,206,537	$ 3,583,605	$ 14,648,309

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13. ABSTRACT *(Maximum 200 words)*
LCC analysis is a powerful tool for investigating the costs of competing systems. This thesis investigates the cost scaling methods to improve the traditional LCC modeling techniques. The motivation for this research is finding a good estimate for the remediation technologies when the contaminant volume is not exactly known. This specific case lead researcher to investigating the methods of cost scaling and effects of inflation in the cost estimation. As a result of study a generic LCC model is developed. Methods for considering inflation and scaling are recommended and embodied into the model. The developed model is applied the specific case and used to analyze the cost of alternative remediation technologies.
Results of the research suggests that scaling can be accomplished with better accuracy if there is data and if the scaling can be performed at the level of cost elements in the cost breakdown structure. Inflation effects can be handle by ignoring or estimating the future inflation rates from the past rates. This study suggests that inflation rate should be investigated, before using general cost indices, for special elements which effects the cost of the system.

14. SUBJECT TERMS
Cost estimating, cost escalation, cost scaling, inflation, remediation technologies, monte carlo simulation.

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