Conference Paper

Improved Decision Making with Sensitivity Analysis

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Introduction & Problem

▸ In constrained budget environments, it is critical for Project Managers to have the ability to understand different decision strategies and perform trade-offs to increase the likelihood of project success

– Estimating models should not only provide accurate forecasts, but also serve as investigative tools that allow Project Managers to explore decision strategies and understand their potential impact on project execution

▸ The fields of Cost Estimation and Program Management often rely on the technique of Sensitivity Analysis (SA) for the purpose of informing management decisions

– SA methods are related to probabilistic estimating models based upon Monte Carlo simulation or similar techniques for combining distributions for uncertainty in model inputs in order to estimate uncertainty in model outputs

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Introduction & Problem

▸ Typical questions SA techniques are used to investigate include:
– What are the greatest risks to program execution?
– What is the impact to a project's performance if a particular risk is mitigated?
– What components of a project are most likely to contribute to cost or schedule growth?

▸ **Shortcomings exist in conventional SA applications:**

– SA metrics are often esoteric and become lost in translation between the analyst and Project Managers – reducing their ability to provide the information needed by decision makers

– Standard SA practices have not kept pace with the increasing complexity of estimating techniques leading to misapplication and misinterpretation of results

– Powerful SA techniques that have been proven effective in other estimating fields are often overlooked because they are not yet part of the standard project estimating lexicon

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Introduction & Problem

▸ In this study, we review two common SA methods to project estimation including a description of each method as well as its advantages and disadvantages

– There are a multitude of methods that may be considered 'popular'; in this study we hone in on two methods the author encounters most frequently in the practice of cost estimation and analysis for project management

▸ Additionally, we explore a less common and novel Sensitivity Analysis techniques that is applicable to a robust class of estimating models including models that currently dominate the field of Integrated Cost and Schedule Risk Analysis

▸ This study seeks to improve the ability of estimating models to serve as a decision informing tools that help project managers make the right choices to mitigate risk and improve the likelihood of program success

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Popular Sensitivity Analysis Methods in Project Estimating

▸ This section hones in on two methods that the author encounters most frequently in the practice of cost estimation and analysis for project management

▸ The intent of this section is to discuss the merits and limitations of each of the following methods:

– Correlation Analysis

– One Factor at a Time Analysis (OFAT Tornado Charts)
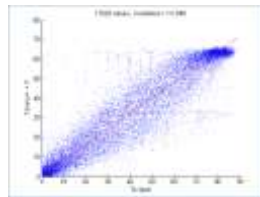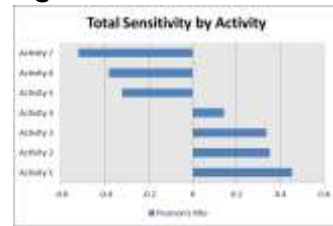

Correlation Analysis
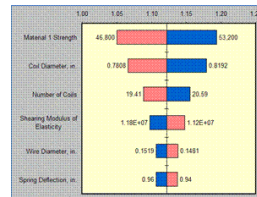
OFAT Tornado Chart

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Popular Sensitivity Analysis Methods in Project Estimating:
Correlation Analysis

▸ Correlation Analysis is the most popular and well known SA method in the fields of Cost Estimation and Program Management … so well known that the below is probably a review for most estimators

▸ Two types of correlation analyses are Pearson correlation and Spearman correlation

– Pearson correlation evaluates the strength of linear association between paired input and output values

– Spearman correlation is a measure of the strength of the monotonic relationship between two variables and can account for monotonic nonlinear relationships

– Correlation analysis measures the effect of one input at a time on the model output. Both Pearson and Spearman correlation coefficients range from -1 to +1, with values close to zero representing a weak relationship

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Popular Sensitivity Analysis Methods in Project Estimating:
Correlation Analysis Advantages & Disadvantages

▸ Pearson Correlation is primarily used in Cost Analysis and Project Management

  – Model inputs ranked by the magnitude of their Pearson Correlation Coefficient with the Model output in ascending order

Correlation Analysis Bar Chart

▸ **Advantages:**

  – Measures the strength of the linear relationship between variables

  – Easy to compute and available in nearly all statistics packages

▸ **Disadvantages:**

  – Pearson coefficients are inaccurate for nonlinear models – the assumption of linearity and normality are critical to interpretation

  – Pearson coefficients cannot directly deal with interactions between inputs

  – Scale of correlation measure is not easy to interpret

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Popular Sensitivity Analysis Methods in Project Estimating:
*Correlation Analysis Interpretation*

▸ Pearson Correlation (Rho) is most easily interpreted when the following assumptions are satisfied by the model

  – The model output is linear in terms of the model inputs

  – The model inputs are i.i.d. and normally distributed (or symmetric, continuous, and otherwise well behaved)

▸ When the above conditions are satisfied Rho can be interpreted in terms of the *Coefficient of Determination* (Rho^2)

  – The coefficient of determination is defined as the percent of the variation in the values of the model output that can be "explained" by variations in the value of a model input

  – If a correlation coefficient of $Rho = 0.50$ is observed then the coefficient of determination is $Rho^2 = 0.25$. This means that 25% of the total variation in the output can be explained by the input

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Popular Sensitivity Analysis Methods in Project Estimating:
Correlation Analysis Interpretation

▸ Estimating Models in Cost Estimation and Project estimation rarely meet the strict assumptions detailed in the previous slide

   – Discrete risks can cause jumps, discontinuity, and non-linearity

   – Inputs are often right skewed

   – Model inputs are usually not independent

▸ Due to the ease of performing Correlation Analysis, it is a good first step for SA

▸ However, when presented with a bar chart of Correlation Coefficients, its important to ask the following question:

   – Is the model linear and are the inputs well behaved and independent?

▸ **If the answer to the above question is 'NO' then Correlation Measures are not sufficient for SA**
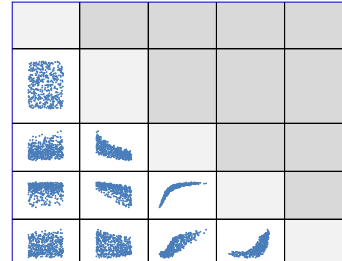
Example of Dependent Model Inputs

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Popular Sensitivity Analysis Methods in Project Estimating:
OFAT Tornado Charts

▸ OFAT based analysis involves the evaluation of a model's output while varying individual model inputs across their possible range

   – Within a Monte Carlo simulation model this process can be explained as follows:

    1. Set All inputs to a central value such as the mode or median

    2. Choose one input and iteratively substitute a set of specified values such as its quantiles while evaluating the model output at each iteration

    3. Perform step 2 for all model inputs

    4. Rank the inputs by the variation in model output that resulted in step 2
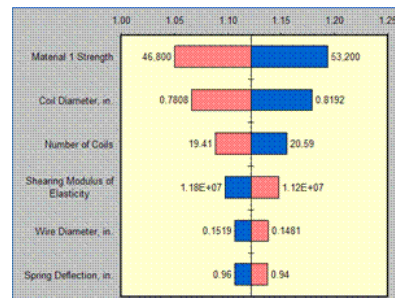
OFAT Tornado Chart

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Popular Sensitivity Analysis Methods in Project Estimating:
OFAT Tornado Charts

▸ **Advantages:**
 – Reports sensitivity measure in units of impact
 – Does not rely on the assumption of linearity or normality

▸ **Disadvantages:**
 – Expensive to compute – requires iterative model evaluation
 – The biggest disadvantage of this method is that it fails to deal with interactions between inputs

▸ Because OFAT analysis does not take into account interdependence between model inputs it can misrepresent the sensitivity of the model to inputs
 – Inputs that have partial impact can be identified as more important than inputs that have higher impacts when interacting with other inputs

▸ **If model inputs are not independent then OFAT analysis are not sufficient for SA**

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Stepwise Regression for Sensitivity Analysis

▸ Stepwise regression is a technique for calculating regression values with multiple input values

▸ The following steps are used in the stepwise regression method:
1. The input with the highest correlation to the output is found and entered into OLS regression equation
2. The partial correlation coefficient of every input that is not in the OLS regression is calculated, and the variable with the largest correlation value is entered into the OLS regression
3. An OLS regression equation is created for every input that has been entered into regression. Each OLS Regression is tested using Bayesian Information Criteria, and insignificant variables are removed
4. Steps 2 and 3 are repeated until the only remaining variables have been rejected from the regression
5. A final regression equation is calculated from the inputs that have not been rejected from the

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Stepwise Regression for Sensitivity Analysis

▸ The result of the step wise procedure is a regression equation with normalized coefficients (β_i) associated with each input

▸ To convert the normalized regression coefficient to an absolute regression coefficient, use the following equation

$$b_i = \beta_i \left(\frac{\sum y^2}{\sum x^2} \right)$$ where

$$\sum y^2 = \sum_{i=1}^{n} Y^2 - \frac{1}{n} \left(\sum_{i=1}^{n} Y_j \right)^2$$ Y_j are the points in the output

$$\sum x^2 = \sum_{j=1}^{n} X_{jj}^2 - \frac{1}{n} \left(\sum_{j=1}^{n} X_j \right)^2$$ X_{jj} are the points in the input

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Stepwise Regression for Sensitivity Analysis

▸ **Interpretation:**
- The b_i value represents the average change in the output corresponding to a one unit change in the associated input
- A positive b_i indicates an increase in the output value when the input increases, while a negative value indicated a decrease
- The regression equations R^2 indicates the percentage of variation explained by the included inputs, if the R^2 value is low then this speaks to the linearity of the model

▸ **Advantages:**
- Easy to interpret sensitivity measures
- Takes into account interdependencies among inputs

▸ **Disadvantages:**

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For further information . . .

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Data Sets and Python Code used in this study are available at:
https://github.com/Blake-Boswell/ICEAA-Sensitivity-Analysis

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