EM600 - Engineering Economics and Cost Analysis

Lecture 11: *Sensitivity Analysis*

- References:
  - Park, Chan S. Contemporary Engineering Economics. New Jersey: Pearson Prentice Hall, 2006 (Chapter 12: 12.2.1, 12.2.2)
  - Eschenbach, Ted G. Engineering Economy: Applying Theory to Practice. New York: Oxford University Press, 2003 (Chapter 17)

- References:
  - Ganguly, A. Engineering Economics Using Excel. New Jersey: SSE, 2008
  - Blank, L. and Tarquin, A. Engineering Economy. New York: McGraw-Hill, 2005 (Chapter 18: 18.1 – 18.2)

After completing this module you should understand the following:

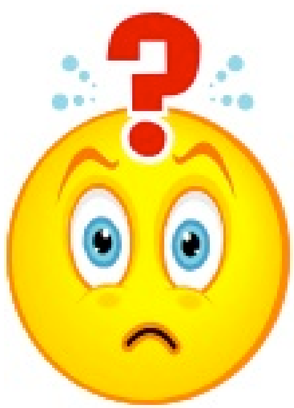
- Overview of break-even analysis
- Overview of sensitivity analysis
- Calculations and graphs used in sensitivity analysis
- Evaluating mutually exclusive alternatives using sensitivity analysis

- Methods of Describing Project Risk
  - **Sensitivity Analysis:** a procedure of identifying the project variables which, when varied, have the greatest effect on project acceptability.
  - **Break-Even Analysis:** a procedure of identifying the value of a particular project variable that causes the project to exactly break even.
  - **Scenario Analysis:** a procedure of comparing a “base case” to one or more additional scenarios, such as best and worst cases, to identify the extreme and most likely project outcomes.

(Chan S. Park, Lecture No46.ppt)

- What is Break-even Analysis?
  - Definitions:
    - ***<u>Break-even analysis</u>*** *is a technique for studying the effect of variations in output on a company's net present worth (or other measure).* (Chan S. Park)
    - ***<u>Break-even volume</u>*** *is the number of units per period required to generate enough revenue so that the net present worth (NPW) is zero.*
  - Can be calculated manually or using Excel Solver software.

- Break-even Analysis:
  - – Example 1: (Chan S. Park, example 12.2)
    - Based on the following financial data, how many units must be sold for this project to break-even?



	0	1	2	3	4	5
Cash Inflows:						
Net salvage						37,389
X(1-0.4)($50)		30*X*	30*X*	30*X*	30*X*	30*X*
0.4 (dep)		7,145	12,245	8,745	6,245	2,230
Cash outflows:						
Investment	-125,000					
-*X*(1-0.4)($15)		-9*X*	-9*X*	-9*X*	-9*X*	-9*X*
-(0.6)($10,000)		-6,000	-6,000	-6,000	-6,000	-6,000
Net Cash Flow	-125,000	21*X* + 1,145	21*X* + 6,245	21*X* + 2,745	21*X* + 245	21*X* + 33,617

- Break-even Analysis:
  - Example 1: (Chan S. Park, example 12.2)
    - Calculate the PW of the Cash Inflows:

$$PW_{\text{inflow}} = (\text{PW of after tax net revenue})$$
$$+(\text{PW of net salvage value})$$
$$+(\text{PWof tax savings from depreciation})$$
$$PW_{\text{inflow}} = 30X(P/A,15\%,5) + \$37,389(P/F,15\%,5) + \$7,145(P/F,15\%,1) + \ldots + \$2,230(P/F,15\%,5)$$
$$PW_{\text{inflow}} = 100.5650X + \$44,490$$

    - Calculate the PW of the Cash Outflows:

$$PW_{\text{outflow}} = (\text{PW of capital expenditure})$$
$$+(\text{PW of after - tax expenses})$$
$$PW_{\text{outflow}} = \$125,000 + (9X + \$6,000)(P/A,15\%,5)$$
$$PW_{\text{outflow}} = 30.1694X + \$145,113$$

- Break-even Analysis:
  - Example 1: (Chan S. Park, example 12.2)
    - Calculate the total NPW:

$$NPW = PW_{\text{inflow}} + PW_{\text{outflow}}$$

$$NPW = 70.3956X - \$100{,}623$$

To calculate the break-even, set NPW = 0 and solve for X

$$0 = 70.3956X - \$100{,}623$$

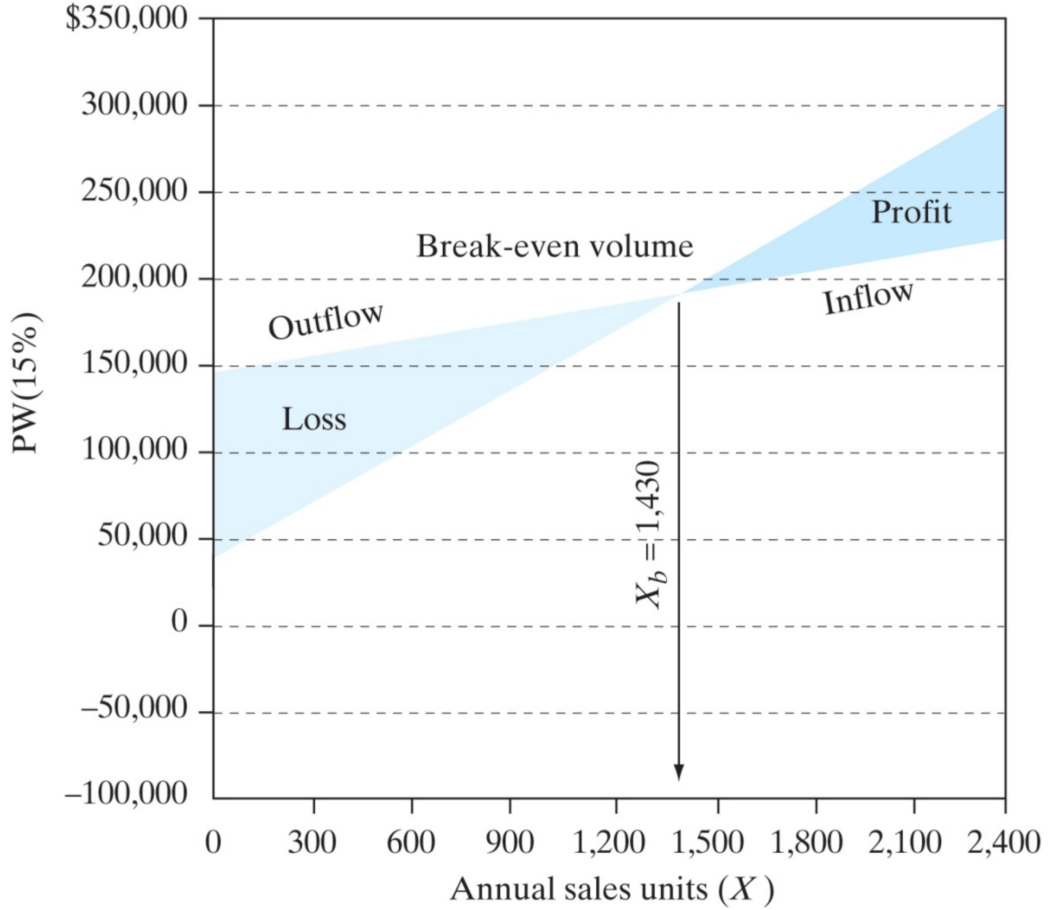
$$X = 1{,}430 \text{ units}$$

- Break-even Analysis:
  - Example 1: (Chan S. Park, example 12.2)
    - NPW as a function of the demand, X

Demand (X)	PW of inflow = 100.5650*X* + $44,490	PW of Outflow = 30.1694*X* + $145,113	NPW = 70.3956*X* - $100,623
0	$44,490	$145,113	-100,623
500	94,773	160,198	-65,425
1000	145,055	175,282	-30,227
1429	188,197	188,225	-28
1430	188,298	188,255	43
1500	195,338	190,367	4,970
2000	245,620	205,452	40,168
2500	295,903	220,537	75,366

- Break-even Analysis:
  - Example 1: (Chan S. Park, example 12.2)
    - Break-even chart:

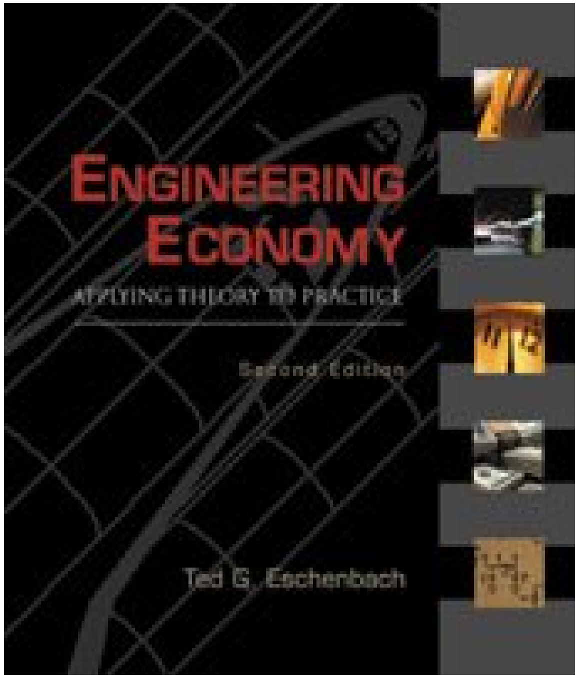
      Break-even volume = 1,430 units



Chan S. Park, Figure 12.2

- What is Sensitivity Analysis?
  - Discussed from an engineering economy perspective.
  - Can be applied to other projects / areas.
  - Similar to experimental design.
  - Sensitivity analysis involves input and output variables:
    - Inputs – volume, unit cost, fixed costs, variable costs, salvage value, interest rate, planning horizon . . . etc.
    - Outputs – net present value or another suitable figure of merit (IRR, EUAC, BCR).

- What is Sensitivity Analysis?
  - Definition: (Ted G. Eschenbach)
    - *Sensitivity analysis examines how a recommended decision depends on estimated input variable values.*
    - Note:
      The estimated input variables are uncertainties.



- What is Sensitivity Analysis?
  - What do you need?
    - Most likely value for the input variable (base case).
    - Upper and lower limits for reasonable changes in the estimated input variable.
  - What can you calculate?
    - The unit impact of these changes on the net present worth or other output variable.
    - The maximum impact of each input variable on the net present worth.
    - The amount of change to crossover a breakeven decision line.

- What is Sensitivity Analysis?
  – Sensitivity analysis can be used to examine uncertainty in all data items that affect the problem's cash flow elements.
  – By comparing their relative impact, sensitivity analysis can then identify which uncertainties are most the important / rank the uncertainties.

- What is Sensitivity Analysis?
  - General Procedure: (Blank & Tarquin)
    - Base Case:
      - Determine which parameters of interest might vary from the most likely estimated value.
    - Sensitivity Analysis:
      - Select the probable range and an increment of variation for each parameter.
      - Select the measure of worth.
      - Compute the results for each parameter, using the measure of worth as a basis.
      - To better interpret the sensitivity, graphically display the parameter versus the measure of worth.

- What is Sensitivity Analysis?
  - Base Case:
    - For the base case, the net present worth (or other suitable worth e.g. IRR, EUAC, BCR) of a proposed project is calculated using the expected values for volume, unit cost, fixed costs, variable costs, salvage value, interest rate, planning horizon . . . etc.
    - The initial values for volume, unit cost, fixed costs, variable costs, salvage value, interest rate, planning horizon . . . etc, are the most likely values expected.
    - ***The base case is used as the starting point for sensitivity analysis.***

- What is Sensitivity Analysis?
  - Sensitivity Analysis:
    - Once the base case has been established, the sensitivity analysis can be started.
    - Each of the estimated input variables (expected values for volume, unit cost, fixed costs, variable costs, salvage value, interest rate, planning horizon . . . etc), is then adjusted by +X% and -Y%, one at a time.
    - **NOTE:**
      - To avoid bias, the limits (+X% and -Y%) for each variable should be established before calculating the net present worth of the base case.
      - +X% and -Y% can be different for each input variable.
    - A new net present worth (or other suitable worth e.g. IRR, EUAC, BCR) is recorded for each adjustment.

- Why do Sensitivity Analysis?
  - It enables you to make better decisions.
  - It helps in deciding which data estimates merit refinement.
  - It helps to focus managerial attention on the key variables during implementation.

- Why is Sensitivity Analysis important?
  - Sensitivity analysis is becoming more important as:
    - Technology and global competition force more rapid change.
    - Competitors increasingly rely on more complete analysis supported by cheaper computing power.

- Why is Sensitivity Analysis important?
  - Engineering economy focuses on how decisions made today will impact a company's financial status in the future.
  - Focusing on the future requires estimations.
  - These estimations are uncertainties which must be analyzed using sensitivity analysis.

- Data uncertainties in Sensitivity Analysis
  - The data used to establish the base case is estimated and therefore uncertainties exist.
  - Limits / data ranges for these uncertainties need to be established.
  - The estimations for the base case data and the limits / data ranges for these uncertainties are typically based on a company's past experiences.

- Data uncertainties in Sensitivity Analysis
  - Example 2: (Eschenbach, example 17.3)
    - Northern Electric is considering a new electric power-generating facility.
    - The following 6 critical input variables have been identified:

Building Cost	$5,000,000
Equipment Cost	$10,000,000
Annual Net Revenue	$2,500,000
Salvage Value	$1,000,000
i	10%
N	20 years

    - How would Northern Electric justify the limits of uncertainty for this project? What limits might they select?

- Data uncertainties in Sensitivity Analysis
  - Example 2: (Eschenbach, example 17.3)
    - Limits of uncertainty selected:

Element	Lower Limit	Base Case	Upper Limit
Building Cost	80%	$5,000,000	150%
Equipment Cost	90%	$10,000,000	110%
Annual Net Revenue	60%	$2,500,000	120%
Salvage Value	70%	$1,000,000	130%
i	60%	10%	150%
N	75%	20 years	150%

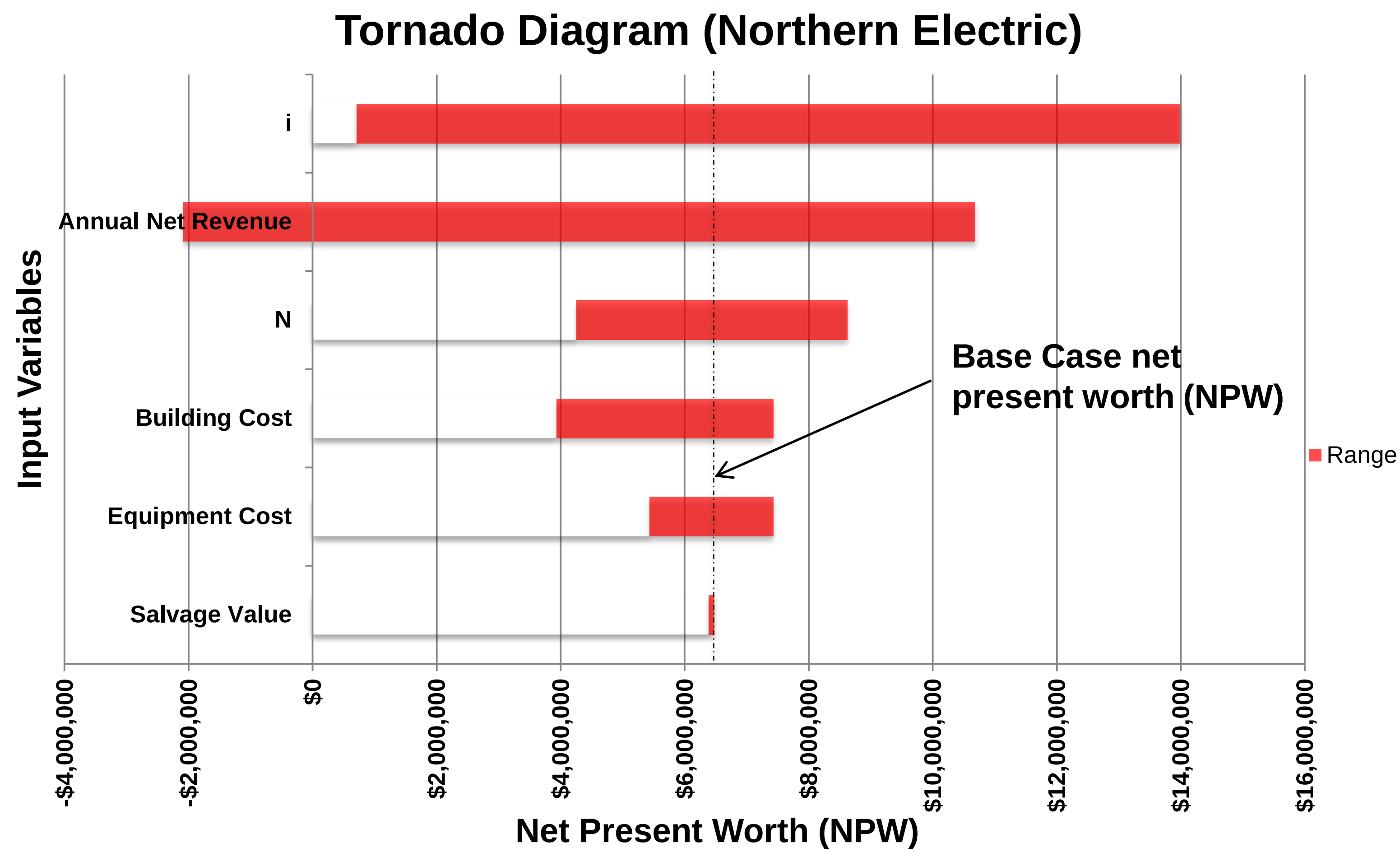
- Data uncertainties in Sensitivity Analysis
  - Example 2: (Eschenbach, example 17.3)
    - Justification for limits of uncertainty selected:
      - Based on previous experience, Northern Electric knows that:
        - » Major buildings cost between 80% and 150% of the estimates used to generate the request for proposals.
        - » Major equipment consists of “off-the-shelf” items with actual costs between 90% and 110% of the estimated costs.
        - » Growth in demand and associated revenues are difficult to predict. Annual net revenues should be within 60% and 120% of the estimated quantity.
        - » The salvage value has an estimated accuracy of 70% to 130%.

- Data uncertainties in Sensitivity Analysis
  - Example 2: (Eschenbach, example 17.3)
    - Justification for limits of uncertainty selected:
      - Based on previous experience, Northern Electric knows that:
        - » The appropriate interest rate for real economic returns over inflation should be between 6% and 15% (60% to 150% of the base case value). This range is large to ensure non-linearities are more apparent.
        - » The project horizon should be between 15 and 30 years (75% to 150% of the base case value).
    - **NOTE:** It is poor practice to examine each variable under the same limits of uncertainty. This can prove to be misleading.

- Techniques in Sensitivity Analysis:
  - Data manipulation:
    - Combines multiple breakeven charts / tables using:
      - Data tables.
      - Tornado diagrams.
      - Spiderplots.
  - Software:
    - Different software packages exist such as:
      - Microsoft Excel, SimLab, Sensitivity Toolkit for Office 2003/2007, . . . etc.
    - For this class Microsoft Excel will be used.

- Techniques in Sensitivity Analysis:
  - Tornado Diagram:
    - Emphasizes the best and worst values of the net present worth (NPW) for each variable under consideration.
    - Tornado "funnel" is created by ordering the variables from those with the most effect (largest range) on the NPW at the top to those with the least effect on the bottom.
    - It ignores the information on the limits to the changes in each variable.

- Techniques in Sensitivity Analysis:
  - Tornado Diagram Sample:

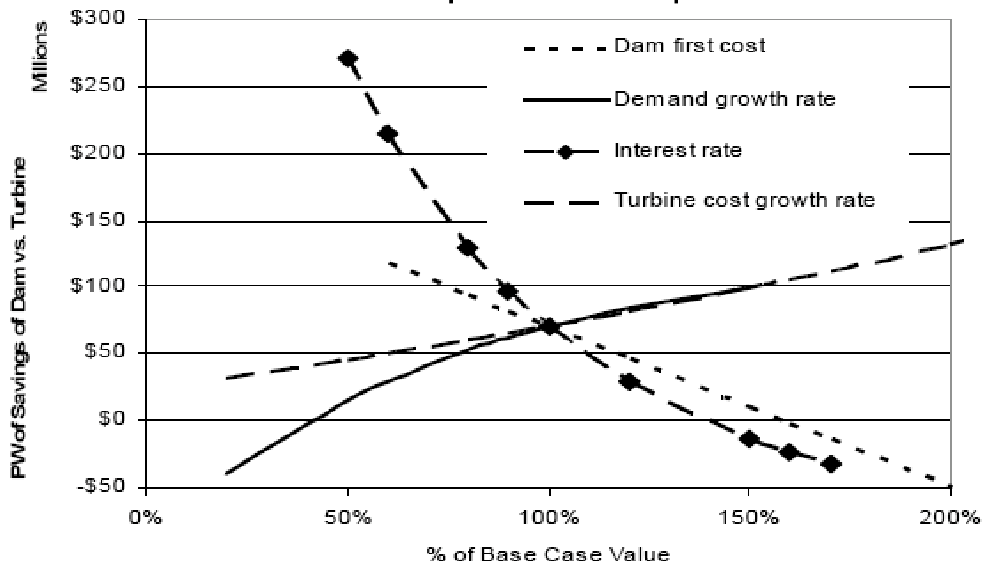


- Techniques in Sensitivity Analysis:
  - Spiderplot:
    - x-axis:
      - Measures all variables in a common unit, the % of each base case value.
        - » Usually the natural units are all different.
        - » This metric works poorly for variables with small or zero base case values. For these variables, natural units work better.
      - Measures the potential uncertainty in the cash flow element (input variable).
    - y-axis:
      - Measures the impact of that uncertainty on the output variable (net present worth, . . . etc)

- Techniques in Sensitivity Analysis:
  - Spiderplot:
    - The base case is recorded in the centre of the plot.
    - Each cash flow element is represented by a curve between its upper and lower limits that passes through the base case point.
    - The steeper the slope of the curve, the more significant the impact of changing this variable has on the value of the output variable.
    - Avoid too many variables (>7) as the plot becomes too busy and less useful.

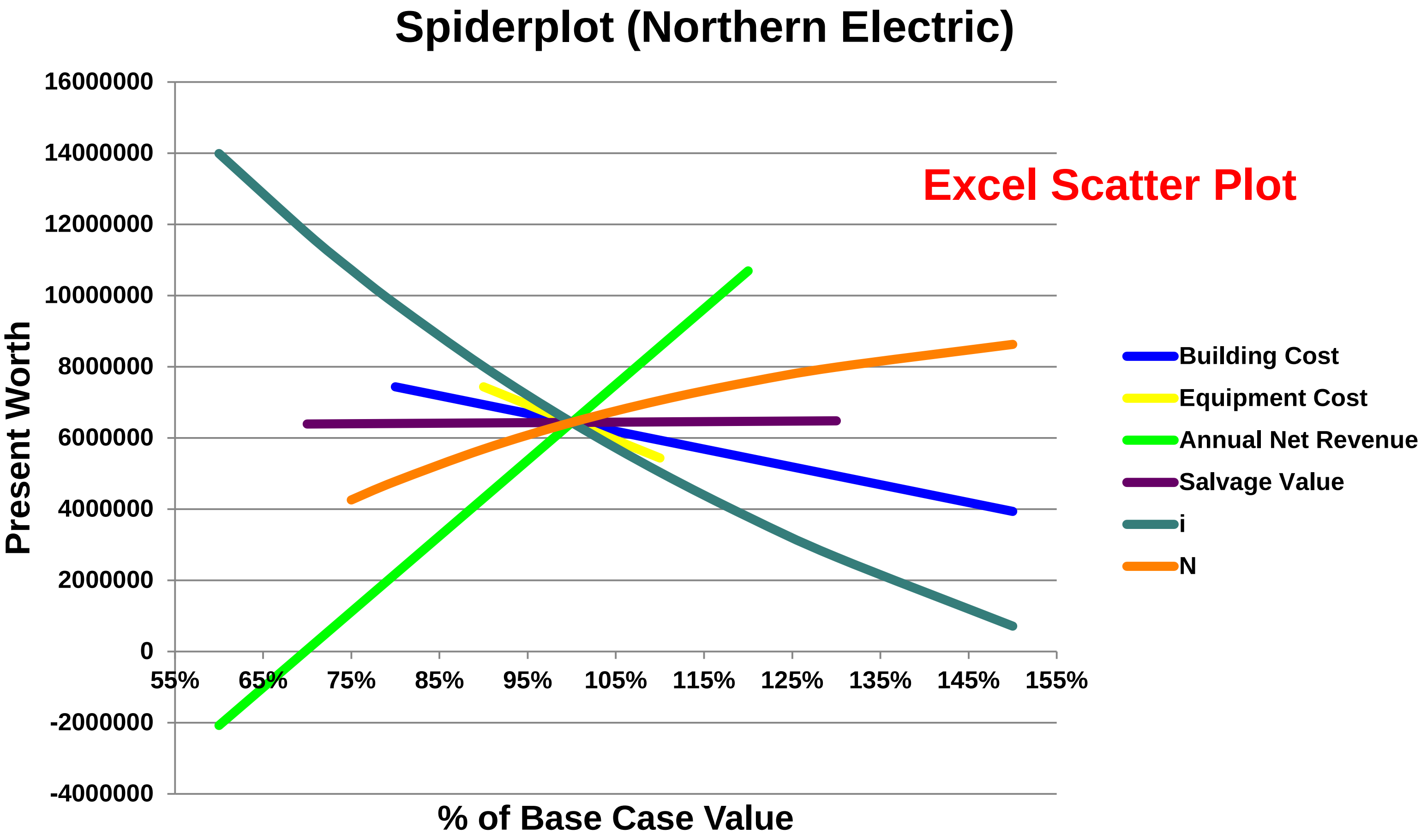
- Techniques in Sensitivity Analysis:
  - Spiderplot:
    - If correctly presented, a spiderplot will depict the:
      - Limits of uncertainty for each cash flow element.
      - Impact of each cash flow element on the output variable (net present worth, . . . etc), measured by the curve's slope.
      - Identification of which cash flow elements will have the biggest impact on the decision to accept or reject the proposed project.

- Techniques in Sensitivity Analysis:
  - Spiderplot:
    - What to expect . . .
      - Input variables such as unit cost, and fixed costs usually have a linear relationship to the net present worth.
      - Input variables such as the interest rate, and the planning horizon exhibit a curved relationship to the net present worth.



Chapters1-4rev12-04.pdf (Ted G. Eschenbach, Figure 4.2)

- Techniques in Sensitivity Analysis:
  - Spiderplot Sample:



- Techniques in Sensitivity Analysis:
  - Data Table:
    - Used to supplement the graphical representation, especially in situations involving a large number of input parameters.
    - Excel, through the use of the built-in function called **'Data Table'** (or **'Table'**, Excel 2003), can be used to determine the impact of any input parameters to the final value of the output.
    - The 'Data Table' function in Excel 2007 can be found under the ribbon titled 'data', in the 'what-if analysis' section.
    - The 'Table' function in Excel 2003, can be found under the 'Data' drop down menu.
    - For further details, refer to Chapter 3, Ganguly, A. Engineering Economics Using Excel. New Jersey: SSE, 2008

- Techniques in Sensitivity Analysis:
  - Data Table:
    - Sensitivity Ratio:
      - Can be calculated using the data table and the following relationships:

$$\text{\% Change of Input Variable from Base Case} = \frac{\text{Input Variable \%} - 100\%}{100\%}$$

$$\text{\% Change in Output Variable} = \frac{\text{New Output Variable} - \text{Base Case Output Variable}}{\text{Base Case Output Variable}}$$

$$\text{Sensitivity Ratio} = \left| \frac{\text{\% Change in Output Variable}}{\text{\% Change of Input Variable from Base Case}} \right|$$

- Techniques in Sensitivity Analysis:
  - Data Table:
    - Sensitivity Ratio:
      - The sensitivity ratio provides the decision maker with an accurate quantitative measure of the degree of sensitivity.
      - The higher the value of the sensitivity ratio, the more sensitive the particular parameter is to the output.

Example: Building cost = $5,000,000 (base case 100%). Vary the Building Cost between 80% and 150% of $5,000,000 (base case) and recalculate the NPV range ($7,432,553 to $3,932,553). As expected, increasing building costs have a negative impact on the NPV.

- Techniques in Sensitivity Analysis:
  - Data Table Sample:
    - Northern Electric
      - Data supports spiderplot and tornado diagram.

% of Base Case Value	Building Cost	Equipment Cost	Annual Net Revenue	Salvage Value	i	N
60%			-$2,081,011		$13,986,608	
70%			$47,380	$6,387,960	$11,743,455	
75%			$1,111,576	$6,395,392	$10,721,642	$4,254,591
80%	$7,432,553		$2,175,771	$6,402,824	$9,759,917	$4,776,901
90%	$6,932,553	$7,432,553	$4,304,162	$6,417,689	$7,999,795	$5,683,389
100%	$6,432,553	$6,432,553	$6,432,553	$6,432,553	$6,432,553	$6,432,553
110%	$5,932,553	$5,432,553	$8,560,944	$6,447,417	$5,032,354	$7,051,697
120%	$5,432,553		$10,689,335	$6,462,282	$3,777,276	$7,563,386
130%	$4,932,553			$6,477,146	$2,648,661	$7,986,269
150%	$3,932,553				$709,429	$8,624,595

Base Case NPW = $6,432,553, values for building cost, equipment cost, …etc as per slide 24.

- Techniques in Sensitivity Analysis:
  - Data Table Sample:
    - Northern Electric
      - Data shows sensitivity ratio analysis for a linear relationship (building cost) and a non-linear relationship (planning horizon, N) with NPW.

% of Base Case Value	% change of input variable from base case	Building Cost (LINEAR)			Planning Horizon, N (NON-LINEAR)		
		NPW	% Change in Output Variable	Sensitivity Ratio	NPW	% Change in Output Variable	Sensitivity Ratio
75%	-25.00%				$4,254,591	-33.86%	1.35
80%	-20.00%	$7,432,553	15.55%	0.78	$4,776,901	-25.74%	1.29
90%	-10.00%	$6,932,553	7.77%	0.78	$5,683,389	-11.65%	1.16
100%	0.00%	$6,432,553	0.00%	N/A	$6,432,553	0.00%	N/A
110%	10.00%	$5,932,553	-7.77%	0.78	$7,051,697	9.63%	0.96
120%	20.00%	$5,432,553	-15.55%	0.78	$7,563,386	17.58%	0.88
130%	30.00%	$4,932,553	-23.32%	0.78	$7,986,269	24.15%	0.81
150%	50.00%	$3,932,553	-38.86%	0.78	$8,624,595	34.08%	0.68

- Techniques in Sensitivity Analysis:
  - Data Table Sample:
    - Northern Electric
      - Data shows sensitivity ratio analysis for a linear relationship (building cost) and a non-linear relationship (planning horizon, N) with NPW.

% of Base Case Value	% change of input variable from base case	Building Cost (LINEAR)			Planning Horizon, N (NON-LINEAR)		
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100%	0.00%	$6,432,553	0.00%	N/A	$6,432,553	0.00%	N/A
110%	10.00%	$5,932,553	-7.77%	0.78	$7,051,697	9.63%	0.96
120%	20.00%	$5,432,553	-15.55%	0.78	$7,563,386	17.58%	0.88
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150%	50.00%	$3,932,553	-38.86%	0.78	$8,624,595	34.08%	0.68

$$= \frac{120\% - 100\%}{100\%}$$

- Techniques in Sensitivity Analysis:
  - Data Table Sample:
    - Northern Electric
      - Data shows sensitivity ratio analysis for a linear relationship (building cost) and a non-linear relationship (planning horizon, N) with NPW.

% of Base Case Value	% change of input variable from base case	Building Cost (LINEAR)			Planning Horizon, N (NON-LINEAR)		
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100%	0.00%	$6,432,553	0.00%	N/A	$6,432,553	0.00%	N/A
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120%	20.00%	$5,432,553	-15.55%	0.78	$7,563,386	17.58%	0.88
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150%	50.00%	$3,932,553	-38.86%	0.78	$8,624,595	34.08%	0.68

$$= \frac{\$5,432,553 - \$6,432,553}{\$6,432,553}$$

- Techniques in Sensitivity Analysis:
  - – Data Table Sample:
    - Northern Electric
      - – Data shows sensitivity ratio analysis for a linear relationship (building cost) and a non-linear relationship (planning horizon, N) with NPW.

% of Base Case Value	% change of input variable from base case	Building Cost (LINEAR)			Planning Horizon, N (NON-LINEAR)		
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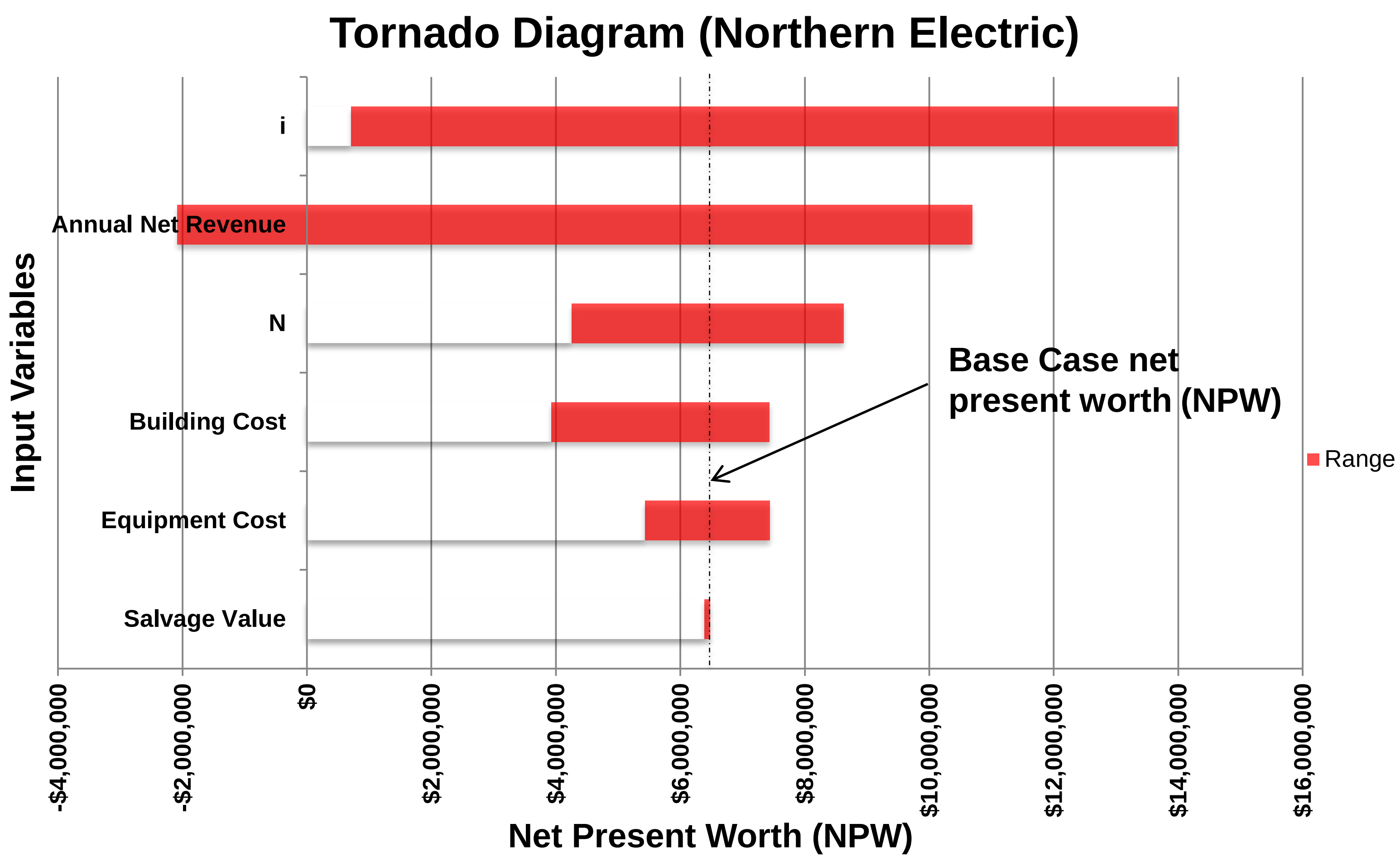
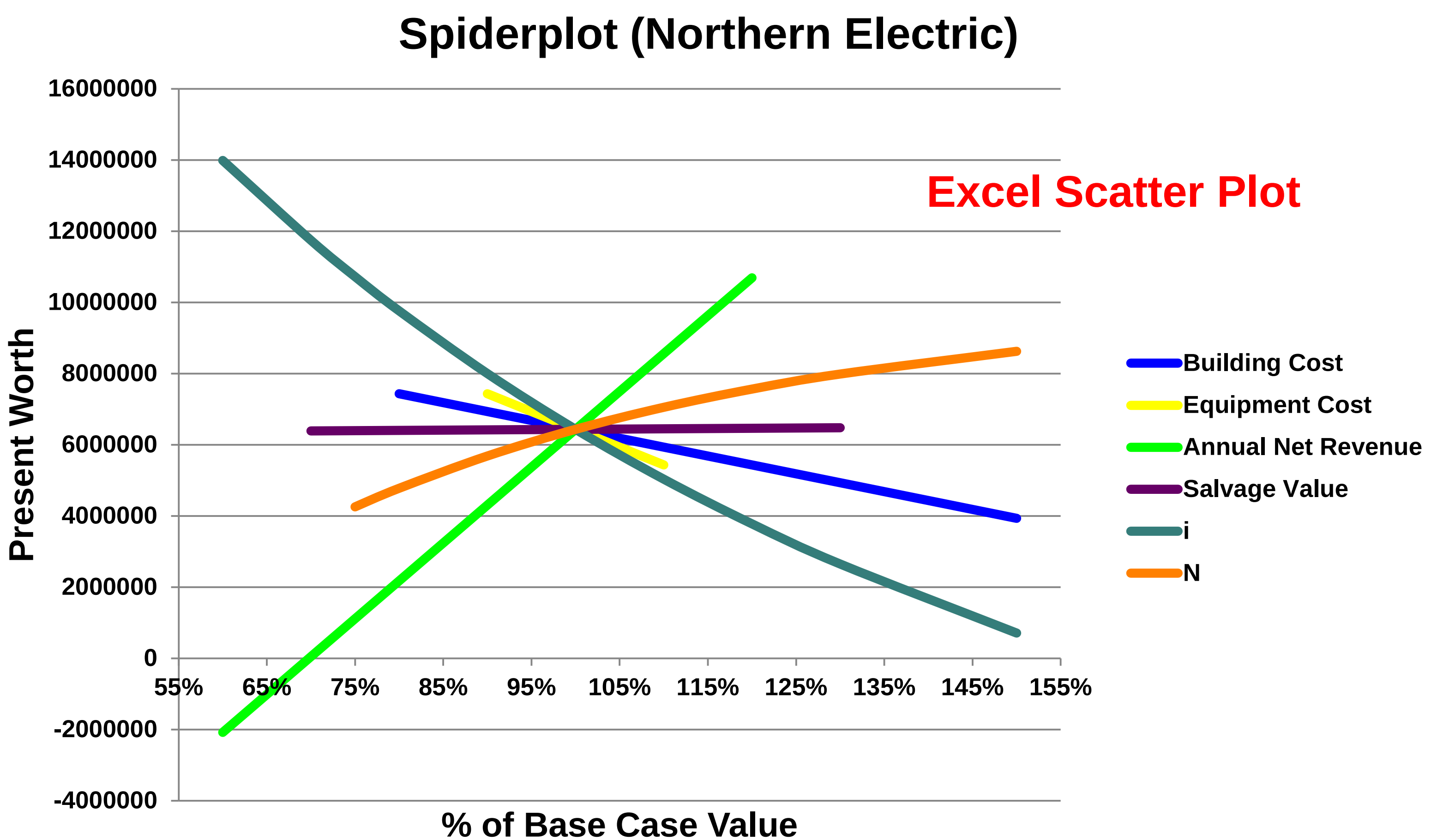
100%	0.00%	$6,432,553	0.00%	N/A	$6,432,553	0.00%	N/A
110%	10.00%	$5,932,553	-7.77%	0.78	$7,051,697	9.63%	0.96
120%	20.00%	$5,432,553	-15.55%	0.78	$7,563,386	17.58%	0.88
130%	30.00%	$4,932,553	-23.32%	0.78	$7,986,269	24.15%	0.81
150%	50.00%	$3,932,553	-38.86%	0.78	$8,624,595	34.08%	0.68

$$= \left| \frac{-15.55\%}{20.00\%} \right|$$

- Techniques in Sensitivity Analysis:



- Techniques in Sensitivity Analysis:



- Sensitivity Analysis: 3 Alternatives
  - Example 3: (Blank & Tarquin, example 18.3)
    - Consider 3 mutually exclusive alternatives with the following financial data:

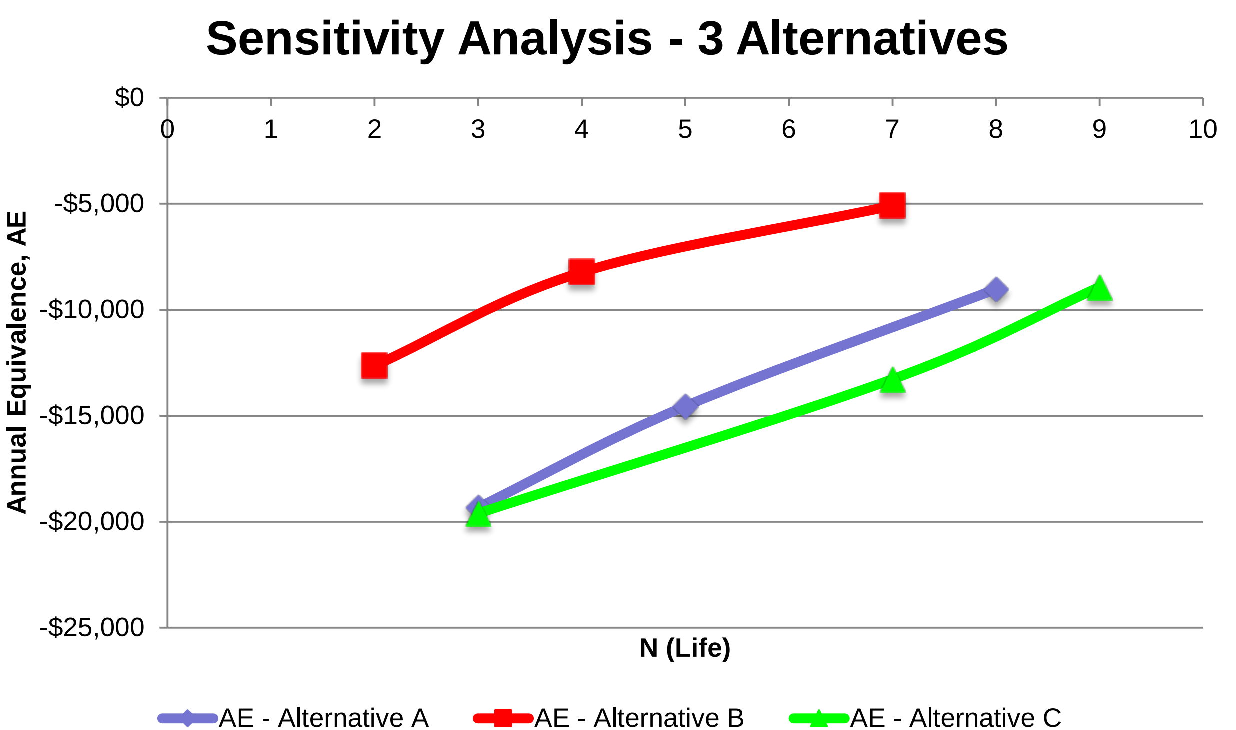
	I	S	Annual Costs	N
Alternative A:				
Worst Case	$20,000	$0	$11,000	3
Base Case	$20,000	$0	$9,000	5
Best Case	$20,000	$0	$5,000	8
Alternative B:				
Worst Case	$15,000	$500	$4,000	2
Base Case	$15,000	$1,000	$3,500	4
Best Case	$15,000	$2,000	$2,000	7
Alternative C:				
Worst Case	$30,000	$3,000	$8,000	3
Base Case	$30,000	$3,000	$7,000	7
Best Case	$30,000	$3,000	$3,500	9

- Sensitivity Analysis: 3 Alternatives
  – Example 3: (Blank & Tarquin, example 18.3)
    - Deliverables:
      – Perform a sensitivity analysis and determine the most economical alternative using:
        » Output variable = annual equivalence, AE
        » MARR = 12%

- Sensitivity Analysis: 3 Alternatives
  - Example 3: (Blank & Tarquin, example 18.3)

$$AE = -P(A/P,i,N) + A + F(A/F,i,N)$$
$$AE = -I(A/P,i,N) + A + S(A/F,i,N)$$

	N (Life)	AE
Alternative A:		
Worst Case	3	-$19,327
Base Case	5	-$14,548
Best Case	8	-$9,026
Alternative B:		
Worst Case	2	-$12,640
Base Case	4	-$8,229
Best Case	7	-$5,089
Alternative C:		
Worst Case	3	-$19,601
Base Case	7	-$13,276
Best Case	9	-$8,927



- Sensitivity Analysis: 3 Alternatives
  - Example 3: (Blank & Tarquin, example 18.3)
    - Conclusion:
      - Obvious alternative to select is alternative B.
        - » Alternative B is has a better annual equivalence when compared with both alternatives A and C for each case (worst, base, best).
      - Decisions are not always this clear cut. Refer to example 4.

- Sensitivity Analysis: 3 Alternatives
  - Example 4:
    - You work at Merck and your boss has asked you to consider the following 3 mutually exclusive sifting machines with the following financial data:

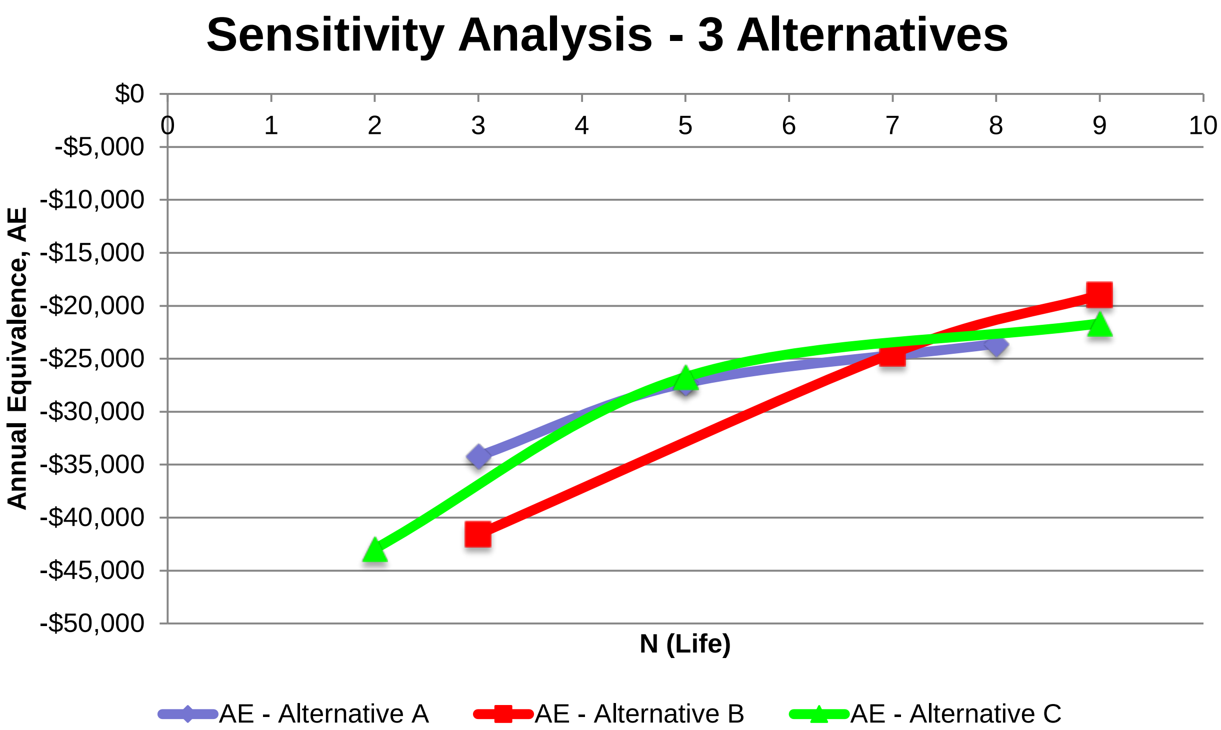
	I	S	Annual Costs	N
Machine A:				
Worst Case	$50,000	$8,000	$15,750	3
Base Case	$50,000	$10,000	$15,000	5
Best Case	$50,000	$12,000	$14,500	8
Machine B:				
Worst Case	$72,000	$11,500	$15,000	3
Base Case	$72,000	$13,000	$10,000	7
Best Case	$72,000	$15,000	$6,500	9
Machine C:				
Worst Case	$55,000	$9,750	$15,000	2
Base Case	$55,000	$9,750	$13,000	5
Best Case	$55,000	$9,750	$12,000	9

- Sensitivity Analysis: 3 Alternatives
  - Example 4:
    - Deliverables:
      - Your boss has asked you to perform a sensitivity analysis and determine the most economical machine to purchase using:
        - » Output variable = annual equivalence, AE
        - » MARR = 12%

- Sensitivity Analysis: 3 Alternatives
  - Example 4:

$$AE = -P(A/P,i,N) + A + F(A/F,i,N)$$
$$AE = -I(A/P,i,N) + A + S(A/F,i,N)$$

	N (Life)	AE
Machine A:		
Worst Case	3	-$34,197
Base Case	5	-$27,296
Best Case	8	-$23,590
Machine B:		
Worst Case	3	-$41,569
Base Case	7	-$24,488
Best Case	9	-$18,998
Machine C:		
Worst Case	2	-$42,944
Base Case	5	-$26,723
Best Case	9	-$21,662



- Sensitivity Analysis: 3 Alternatives
  - Example 4:
    - Conclusion:
      - No clear cut conclusion.
      - The decision would have to be based on one of the estimates:
        - » Worst case or
        - » Base case or
        - » Best case
      - What would you do? Why?