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Graphical Display of the Effect of Three Cash Flow Elements for Sensitivity Analysis

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GRAPHICAL DISPLAY OF THE EFFECT OF THREE CASH FLOW ELEMENTS FOR SENSITIVITY ANALYSIS

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ABSTRACT

GRAPHICAL DISPLAY OF THE EFFECT OF THREE CASH FLOW ELEMENTS FOR SENSITIVITY ANALYSIS

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Sensitivity analysis is one of the most important analysis techniques in a decision making process. The analytic intent behind sensitivity analysis is the variation of parameters in data models, and the examination of the effect of these variations on the outcome of the models. There are four primary benefits from conducting a sensitivity analysis: a) sensitivity analysis facilitates the decision makers' development of recommendations, b) sensitivity analysis serves as a tool for communication among stakeholders or decision makers in a project or an organization, c) sensitivity analysis increases overall understanding of the decision models, and d) sensitivity analysis serves as a useful tool in decision model development. Sensitivity analysis in engineering economy can be divided into two main categories. The first one is called one-parameter-at-a-time analysis. This analysis assumes that all parameters or cash flow elements except one are held constant. The second category is the analysis of more than one parameter at a time. This research explored graphical display of three-at-a-time sensitivity analysis in engineering economy. This analysis approach required extensive information to be displayed and decisions to be made in an information-rich domain.

This increased information complexity is harder to represent in conventional two-dimensional displays creating the need for display innovations that support the sensitivity analysis tasks of exploration, understanding, and decision making. Problems with current two-dimensional information representation techniques include limited dimensionality and limited amounts of information that can be portrayed in a display. While three-dimensional information displays offer promise in resolving those issues, there is a lack of empirical evidence to support the appropriateness of using three-dimensional display for sensitivity analysis of three cash flow elements in engineering economy. A three-dimensional information display was designed and an experiment was conducted which tested this three-dimensional integrated display against the traditional two-dimensional bar chart. Recommendations were made for the most immediate needs for future research based on existing gaps in the body of knowledge in engineering management, engineering economy and human computer interaction.

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I thank my family for their continuous support over the years. My mother, father, and brother are a tremendous source of strength for me and I appreciate them dearly.

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CHAPTER I

INTRODUCTION

Sensitivity analysis is one of the most important analysis techniques in a decision making process. The analytic intent behind sensitivity analysis is "the variation of the parameters in a data model, and the examination of the effect of this variation on the outcome of the models" (Pothanun & Dryer, 2002, 42). Sensitivity analysis is an analysis used to manage uncertainty in a decision model or engineering project. Uncertainty in a decision model or engineering project can have many origins. It may be due to incomplete information, fluctuations inherent in the problem, dynamically changes of system, unpredictable changes in future, or a combination of these.

There are four primary benefits for conducting a sensitivity analysis (Arsham, 1994). First, sensitivity analysis facilitates the development of recommendations by the decision makers. Sensitivity analysis can test the robustness of a decision model, an engineering project, or an optimal solution. It also identifies critical parameters, values or ranges of values, thresholds, or break-even values where the recommended strategy changes. It helps decision makers to develop flexible recommendations, dependent on the circumstances, and to compare the values of complex decision strategies. Second, sensitivity analysis can serve as a tool for communication among stakeholders or decision makers in a project or an organization. It makes recommendations more credible, understandable, compelling, or persuasive (Arsham, 1994). From a managerial standpoint, it allows decision makers, such as project managers, to select appropriate assumptions and possible decision strategies. Third, sensitivity analysis increases overall understanding of the decision models. It provides understanding of relationships between input and output parameters. In appropriate situations, it can be used for what-if analysis in engineering projects. Fourth, sensitivity analysis serves as a useful tool in decision model development. It increases the validity and accuracy of a decision model. It also prioritizes acquisition of information.

Sensitivity analysis can be used in many kinds of models including engineering economy models. With sensitivity analysis, decision makers can make changes to key model input parameters or cash flow elements and assess resulting changes to model outcomes and recommendations. Unexpected or non-intuitive changes can indicate decision model weaknesses and point to recommended changes in the decision analysis modeling methodology.

Sensitivity analysis in engineering economy can be divided into two main categories. The first one is called one-parameter-at-a-time analysis. This analysis category has all parameters or cash flow elements except one held constant. The second category is the analysis of more than one parameter at a time. It is also called analysis of the combined effects of uncertainty in two or more cash flow elements on the economic measure of merit (Sullivan, Wicks, & Luxhoj, 2002). According to Haimes (1998), uncertainty is the inability to determine the true state of affairs of a system. It can be caused by incomplete knowledge, stochastic variability or the inability to predict future events. In this analysis category, two or more cash flow elements are changed at the same time while holding the rest of the cash flow elements constant.

One-parameter-at-a-time analysis and the combined effects of two parameters are well supported with current sensitivity analysis graphical displays in engineering economy (Butler & Olson, 1999; Eschenbach, 1992; Eschenbach & McKeague, 1989; Fleischer, 1994; Park, 2001; Sullivan et al., 2002; White, Case, Pratt, & Agee, 1998). Unfortunately, there is limited of academic research on sensitivity analysis graphical display for the combined effects of three or more cash flow elements (Canada, Sullivan, & White, 1995; Fleischer, 1994; Sullivan et al., 2002).

Purpose of Study

The purpose of this research is to improve decision makers' understanding of the combined effects of three cash flow elements in an engineering economy analysis via three-dimensional graphical display comparing to sensitivity analysis bar chart.

Significance of this Research to Engineering Management

According to the American Society for Engineering Management or ASEM (2004), "engineering management is the art and science of planning, organizing, allocating resources, and directing and controlling activities which have a technological component." Engineering management has three dimensions: the technical dimension, the human dimension, and the technology dimension. The technical dimension can be further divided into system engineering, decision science, engineering economy, simulation and, modeling, and project management. The human dimension can be divided into many major subcategories and one of them is visualization. Visualization attempts to display structural relationships and context, that would be difficult to detect by individual retrieval requests (Card, Mackinlay, & Shneiderman, 1999; Card, Robertson, & Mackinlay, 1991).

Visualization has been well utilized in the technical dimension of Engineering Management (Dryer, Peterson, & Pothanun, 2003). Unfortunately, in certain domains visualization has not been used extensively. One of those domains is sensitivity analysis in engineering economy. Figure 1 shows how the current research fits into engineering management body of knowledge.

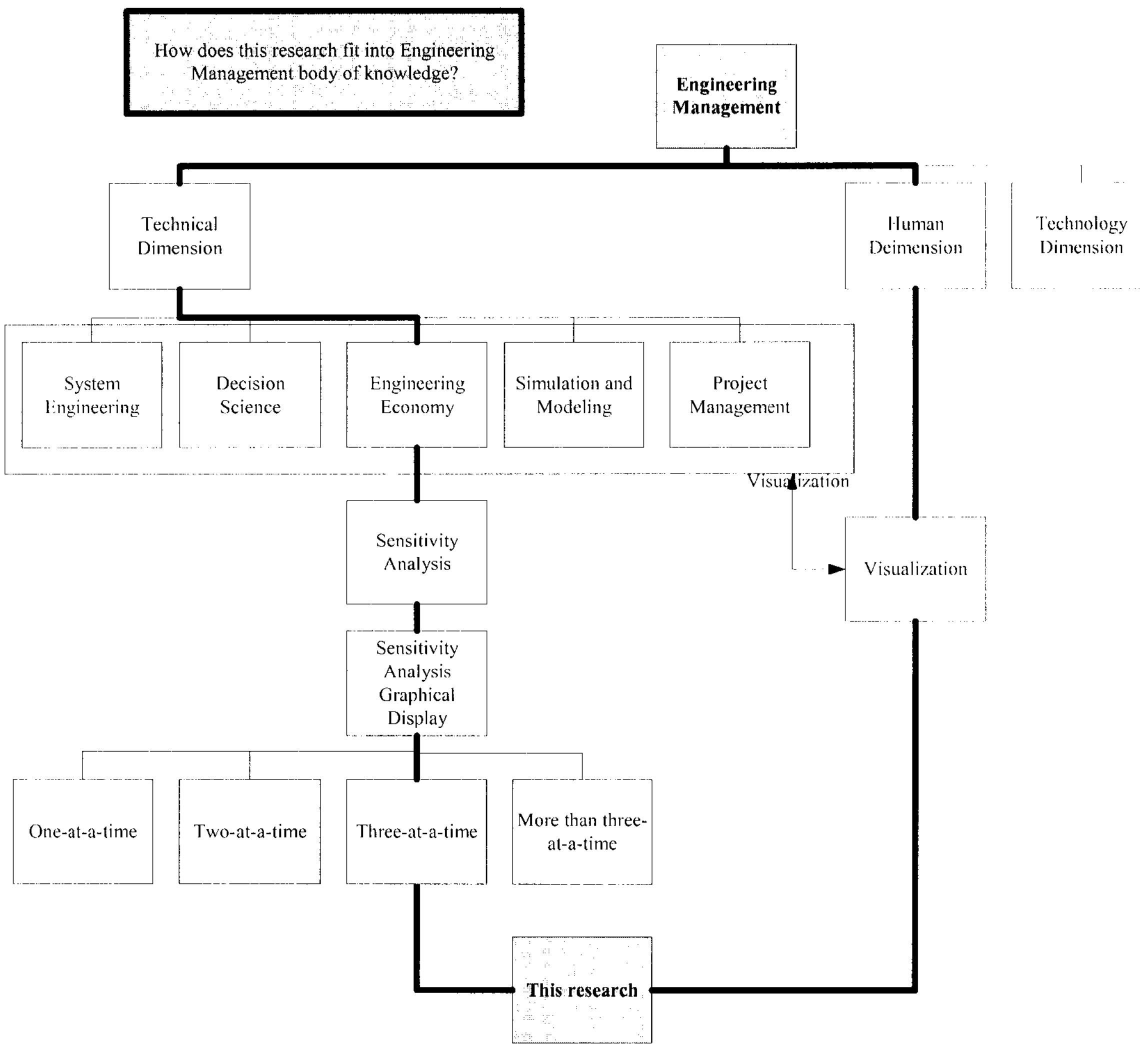


Figure 1 Engineering Management Body of Knowledge

Problem Definition

The specific problem addressed by this research is that there are limitations of scientifically-based graphical displays for sensitivity analysis of the combined effects of three cash flow elements in engineering economy to support management decisions (Butler, Jia, & Dyer, 1997; Butler & Olson, 1999; Canada et al., 1995; Eschenbach, 1992, 2003; Eschenbach & McKeague, 1989)

Research Question

The proposed three-dimensional graphical display will significantly improve decisions and understanding of the combined effects of three cash flow elements as compared to the two-dimensional sensitivity analysis bar chart.

Research Hypothesis

The investigated hypotheses were:

1. The accuracy score for the understanding of the combined effects of three cash flow elements is predicted to be better for the proposed three-dimensional graphical display as compared to the two-dimensional sensitivity analysis bar chart.
2. The latency for understanding of the combined effects of three cash flow elements is predicted to be better for the proposed three-dimensional graphical display as compared to the two-dimensional sensitivity analysis bar chart.

CHAPTER II

LITERATURE REVIEW

Sensitivity analysis in engineering economy, in general, means the relative magnitude of change in the economic measure of merit (such as Present Worth (PW) or Internal Rate of Return (IRR)) caused by one or more changes in estimated study parameter values (Sullivan et al., 2002). According to Newnan, Lavelle, and Eschenbach (2002, 342), sensitivity analysis is an analysis to compute "what variation to a particular estimate would be necessary to change a particular decision." It highlights the important and significant aspects of the problems. Sensitivity analysis also examines "how uncertainty in estimated cash flows influences recommended decisions" (Eschenbach, 2003, 447). Based on Blank and Tarquin (2002, 592), sensitivity analysis determines "how a measure of worth- PW, AW, ROR, or B/C- and the selected alternative will be altered if a particular parameter or cash flow element varies over a stated range of values." Canada et al. (1995) defined sensitivity analysis as a procedure for describing analytically the effects of risk and uncertainty on capital projects. Canada et al. (1995, 289) also stated that:

> "Sensitivity analyses are performed when conditions of uncertainty exist for one or more parameters. The objectives of a sensitivity analysis are to provide the decision maker with information concerning (1) the behavior of the measure of economic effectiveness due to errors in estimating various values of the parameters and (2) the potential for reversals in the preferences for economic investment alternatives."

Canada and Sullivan (1989) supported that sensitivity analysis should answer how changes in judgments would affect the decision outcome. According to Park (2001), sensitivity analysis determines the effect on the Net Present Worth (NPW) or other economic measure of merit of variations in the input variables (such as revenues, operating cost, and salvage value) used to estimate after-tax cash flows. "A sensitivity analysis reveals how much the NPW will change in response to a given change in an input variable" (Park, 2001, 636).

Decision makers are typically interested in the full range of possible outcomes that might result from variances in estimates. "Sensitivity analysis permits a determination of how sensitive final results are to changes in the values of the input estimates" (Thuesen & Fabrycky, 2000, 508). Park and Sharp-Bette (1990, 565) defined sensitivity analysis from a managerial point of view, as they stated that "sensitivity analysis deals with the consequences of incremental change how much could the manager's subjective assessment of chances be altered before the optimal decision would shift." According to White et al. (1998), sensitivity analysis also reduces the amount of information needed to make good decision. Instead of needing a point estimate for an important cash flow element (i.e., interest rate, unit price, initial investment) a range or interval estimate might be sufficient. This will reduce the cost of getting perfect or near perfect information. It also makes more realistic the economic comparison of recommendations or investment alternatives.

Sensitivity analysis is one of the main steps in engineering economic decision making as shown in Figure 2. Adapted from Young (1993) and Bowman (2003), engineering economic decision making consists of seven following steps. First, the need for an economic analysis should be recognized. Second, the decision model needs to be formulated. At this step, it consists of summarizing the certainty and uncertainty of cash flow parameters, establishing criteria for estimating and evaluating consequences, and mathematically determining the uncertainty in the decision model. Third, alternatives or recommendations can be generated at this step including establishing technical understanding of alternatives or recommendations and estimating consequences of alternatives (costs and benefits). Fourth, the decision maker selects the preferred alternative or recommendation. Fifth, sensitivity analysis can be conducted with an option of return to earlier steps. At this step, the decision maker should consider the effect of noneconomic factor on the preferred alternative or recommendation. Sixth, economic and noneconomic factor should be combined to make final decision. Seventh, the final decision can be documented, communicated, and implemented.

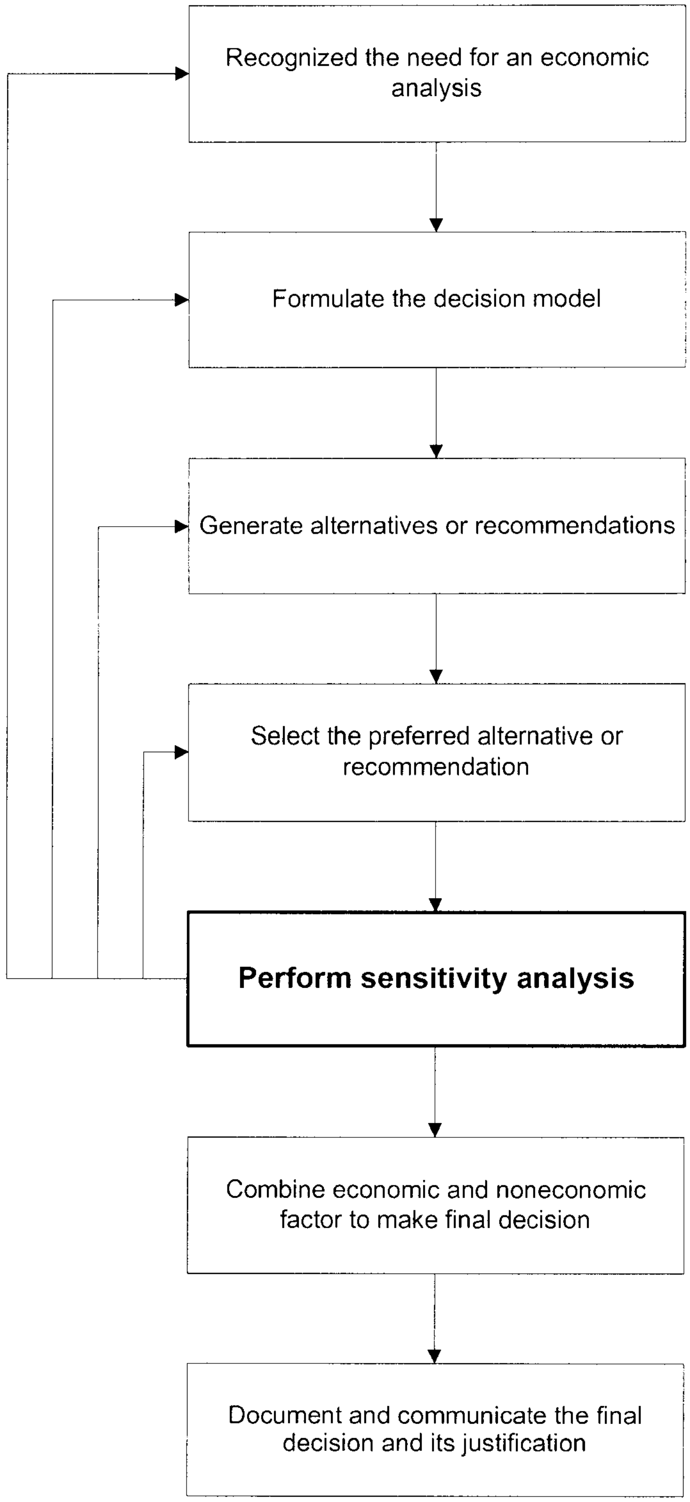


Figure 2 Steps in Engineering Economic Decision Making

Sensitivity analysis is very helpful in the decision making process in engineering economy because all estimates, alternatives, or parameters are subject to some uncertainty (Grant, Ireson, & Leavenworth, 1990). It serves as an intermediate step between the first part of the whole process or the numerical analysis and the second part or the final recommendation in the engineering economic decision making process. The results of the sensitivity analysis can lead to modifications of earlier steps (formulating the decision model, generating alternatives or recommendations, etc.). The results can be weighted in the final alternative or recommendation as well.

Sensitivity Analysis Graphical Displays in Engineering Economy

Sensitivity analysis in engineering economy can be divided into two categories: One-parameter-at-a-time analysis and Two-or-more-parameter-at-a-time analysis or the combined effects analysis. Graphical displays for one-at-a-time analysis are line graphs (spiderplot and break-even chart) and bar charts (including Tornado diagram). These graphical representations tend to have high visual impact; with proper designs, they can make it easier for decision makers to quickly and correctly assess the situation (Eschenbach & McKeague, 1989). According to Sullivan et al. (2002), a break-even chart is commonly used when the selection among project alternatives or the economic acceptability of an engineering project is heavily dependent upon a single factor or cash flow element. Figure 3 and Figure 4 show examples of graphical display of one-at-a-time analysis and break-even chart respectively.

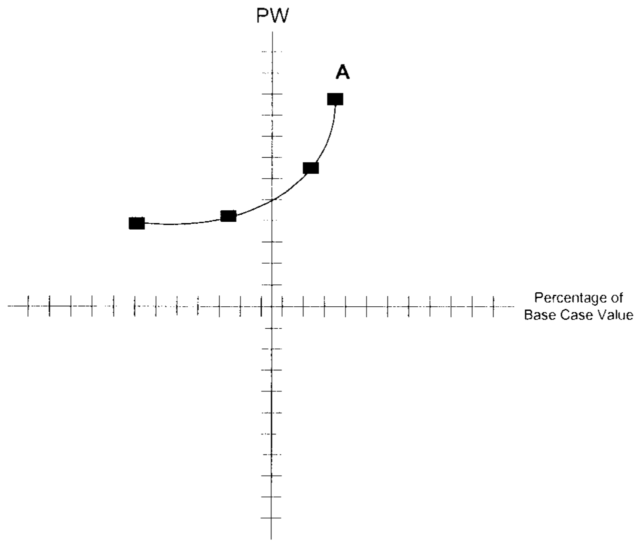


Figure 3 One-at-a-time Sensitivity Analysis Graphical Display
(Adapted from White et al., 1998, 180)

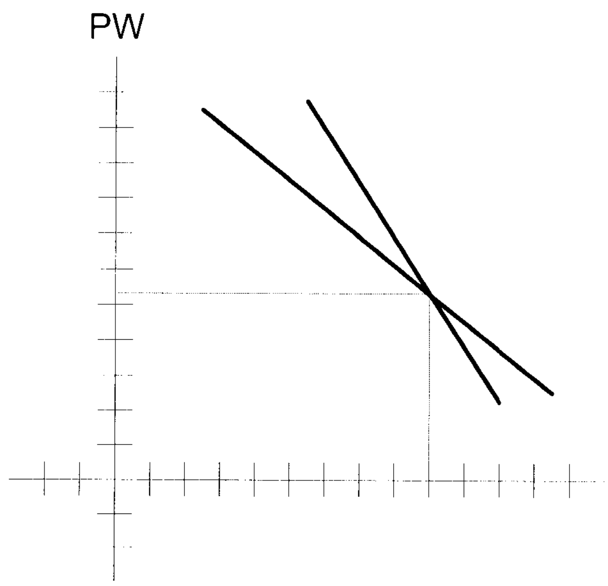


Figure 4 Break-even Chart
(Adapted from Newnan et al., 2002, 346)

According to Park (2001), sensitivity analysis begins with a base-case situation, which is developed using the most-likely values for each input. The decision makers then change the specific variable of interest by several specified percentages above and below the most-likely value, while holding other variables constant. Then a new economic measure of merit (i.e., PW) can be calculated for each of these values. A convenient and useful way to present the results of a sensitivity analysis is to plot spiderplot diagram as shown in Figure 5. The slops of the lines show how sensitive the economic measure of merit (i.e., PW) is to changes in each of the cash flow elements. The steeper the slope, the more sensitive the economic measure of merit is to a change in a particular variable.

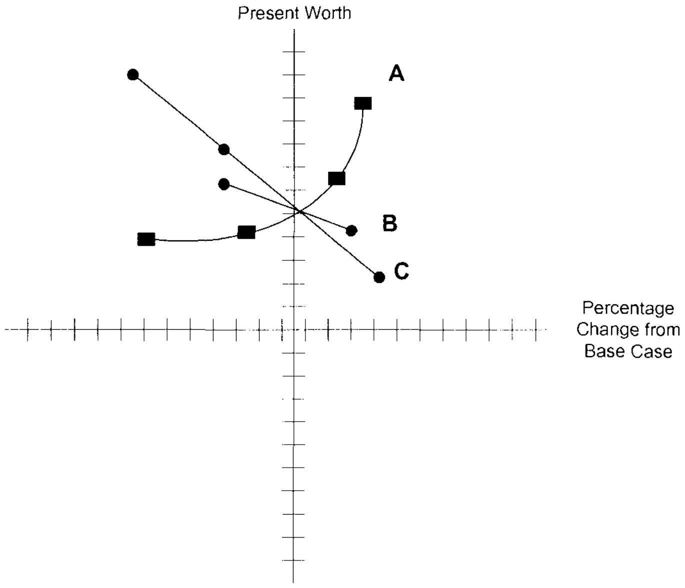


Figure 5 Spiderplot Diagram
(Adapted from Eschenbach, 2003, 455)

A Tornado diagram quickly highlights those variables to which the outcome is most sensitive. Such a diagram can include many variables, and it can also be constructed as a horizontal bar chart (Eschenbach, 1992). Figure 6 and Figure 7 show examples of a Tornado diagram and a horizontal bar chart respectively.

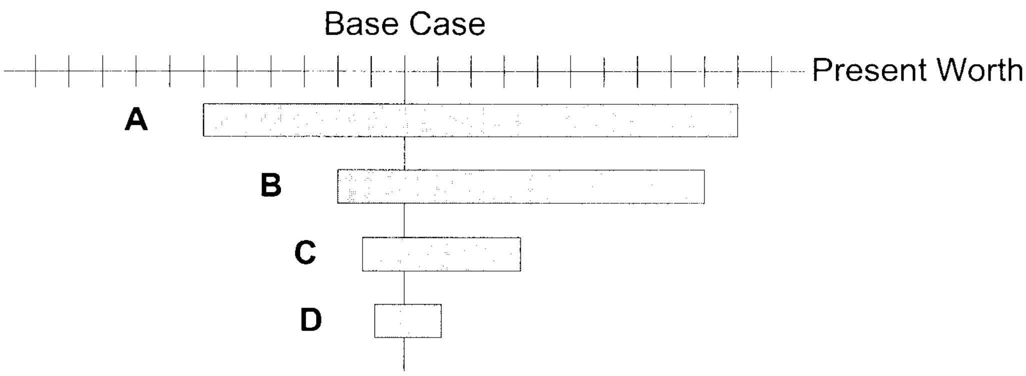


Figure 6 Tornado Diagram
(Adapted from Eschenbach, 1992, 42)

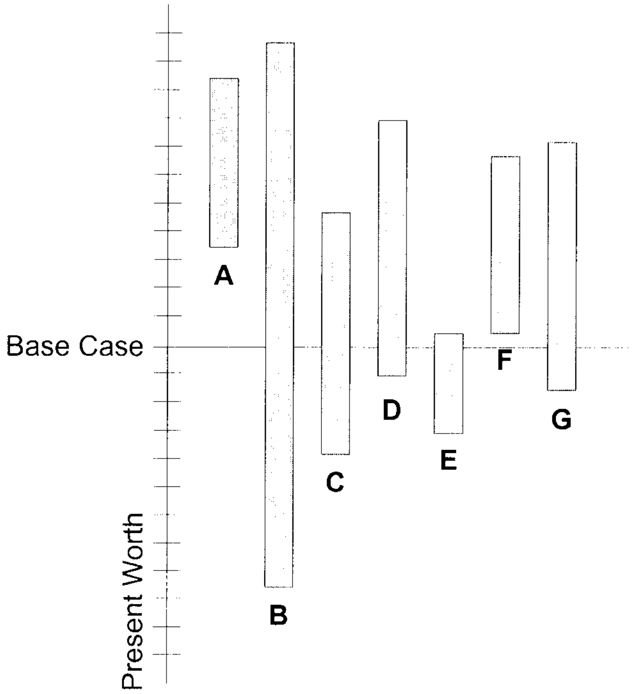


Figure 7 Horizontal Bar Chart
(Adapted from Eschenbach & McKeague, 1989, 324)

Graphical display for one-at-a-time sensitivity analysis provides a useful means to communicate the relative sensitivities of the different cash flow elements on the corresponding economic measure of merit. However, those graphical displays do not explain any interactions among the cash flow elements and the single attribute approach can be misleading as it ignores the potential model interactions that can result from simultaneous manipulations of multiple cash flow elements (Butler & Olson, 1999). Current graphical display for sensitivity analysis of the combined effects of two cash flow elements is constructed using area chart as presented in Figure 8. The shaded area reflects the possible economic measure of merit (i.e., PW) values resulting from all combinations of two interesting variables, which are P (capital investment) and A (annual net cash flow). The shaded area also shows all the possible values and defines the region of uncertainty. At the same time, it indicates the maximum value and the minimum value of the P (capital investment). Since the shaded region is not all above the abscissa or all below the abscissa the decision is sensitive to the combined effect of these two variables.

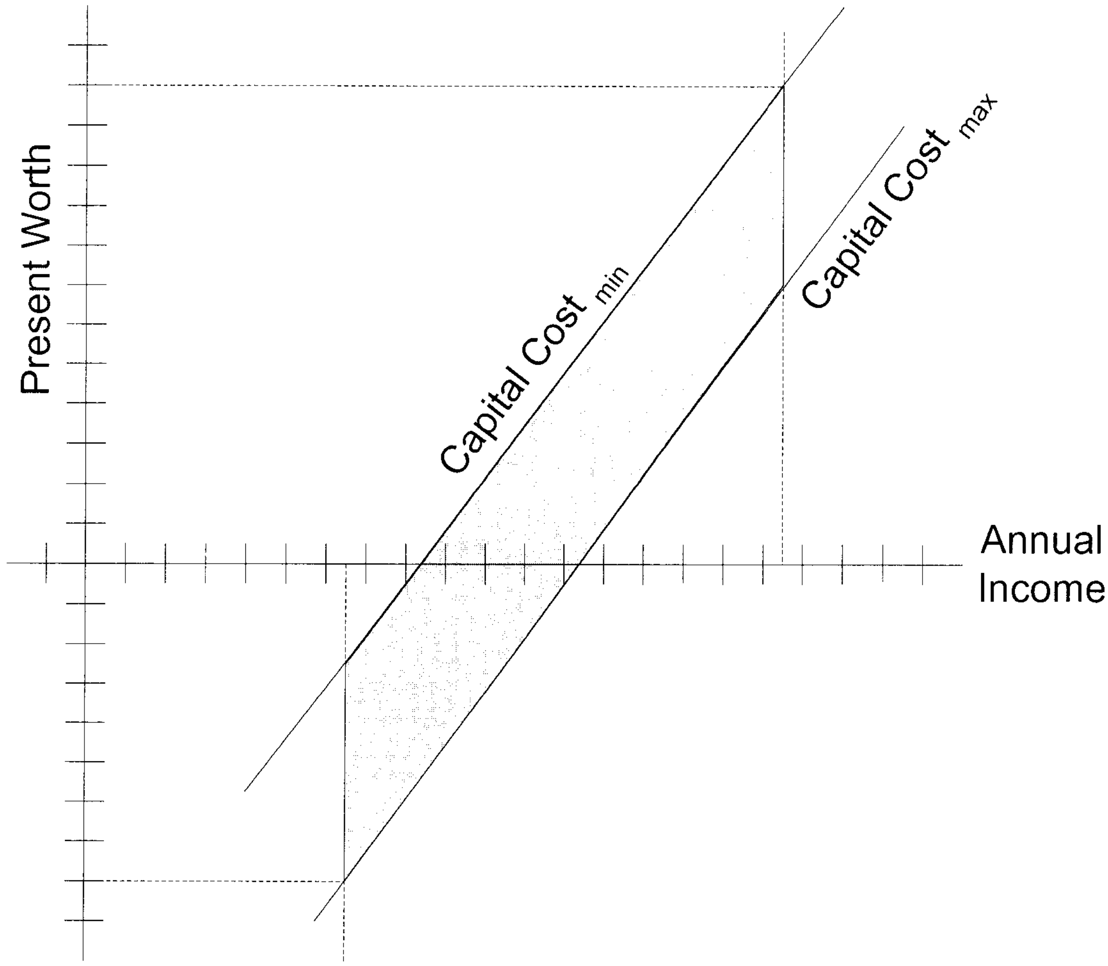


Figure 8 Sensitivity Graph for the Combined Effects of Two Cash Flow Elements
(Source: Sullivan et al., 2002, 461)

Another approach to sensitivity analysis for the combined effects of two cash flow elements is to present it in a percent deviation format or percent changes from base case with an estimation error zone as shown in Figure 9 (Fleischer, 1994; White et al., 1998). Figure 9 presents ± 20% estimation error zone along with favorable and unfavorable regions.

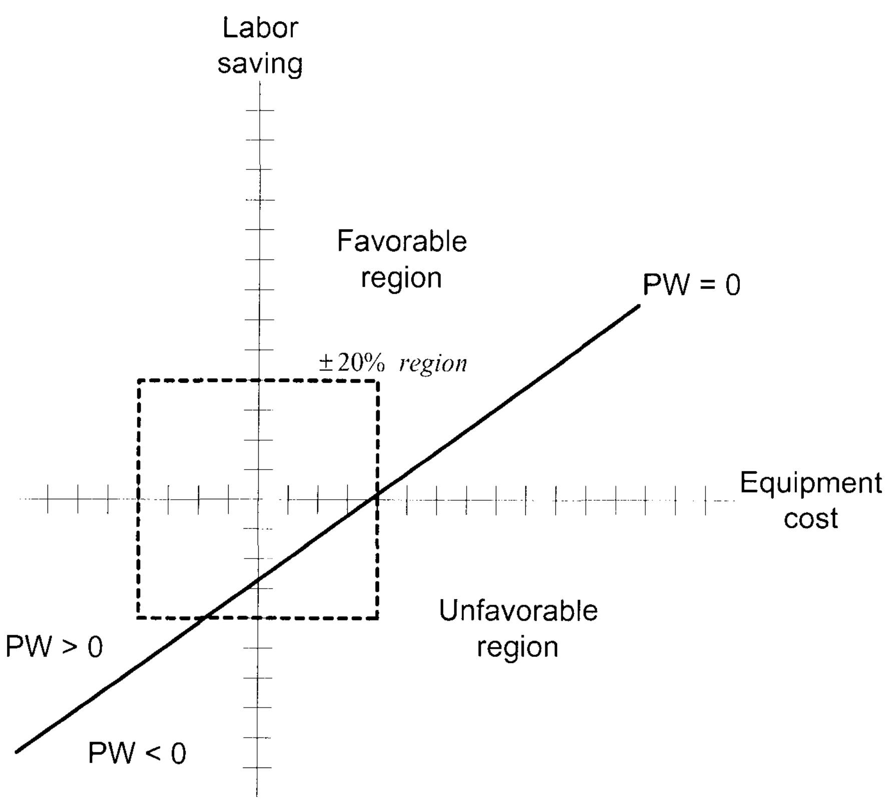


Figure 9 Sensitivity Graph for the Combined Effects of Two Cash Flow Elements with Percent Deviation Region

(Adapted from Fleischer, 1994, 358)

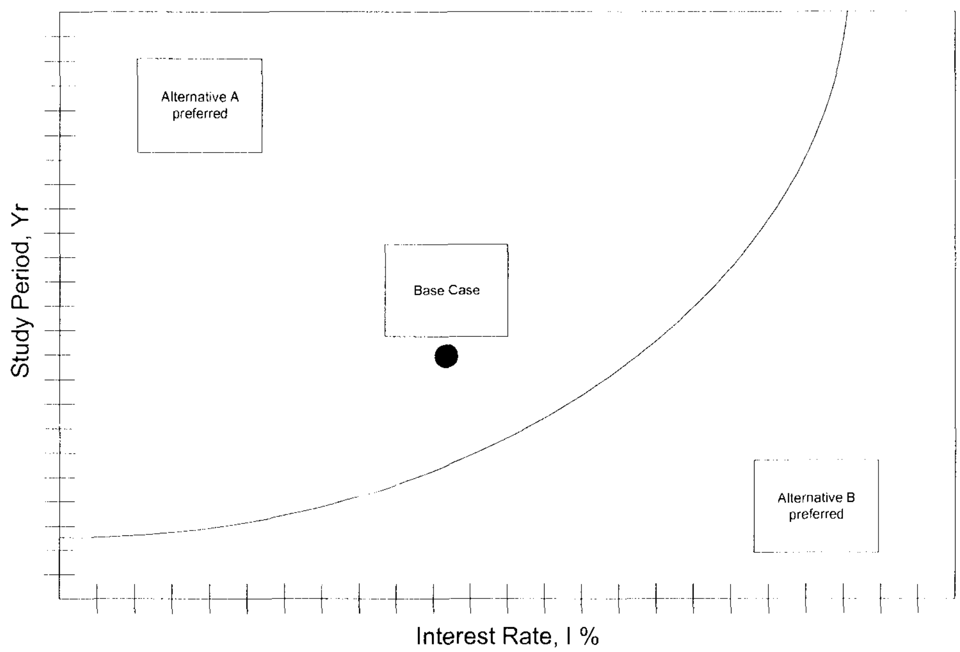


Figure 10 Two-variable Breakeven Curve
(Adapted from Eschenbach & McKeague, 1989, 327)

According to Eschenbach and McKeague (1989), two-at-a-time sensitivity analysis in engineering economy can be presented with a two-variable breakeven curve as shown in Figure 10. In Figure 10, the two interesting variables were plotted against each other in the same chart. The breakeven curve indicates the transition area from alternative A preferred area to alternative B preferred area. The base case location indicated the combination of the most likely values of the two variables. Any combination of the variables above the line will favor one alternative, while below the line will favor the other alternative. One of the limitations of this chart is that it cannot present the values of economic measure of merit (i.e., PW) in the chart.

Currently, the closest analysis of sensitivity analysis for three cash flow elements considered simultaneously is optimistic-pessimistic analysis. The optimistic-pessimistic analysis involves changing estimates of one or more cash flow elements in a favorable outcome (optimistic) direction and in an unfavorable outcome (pessimistic) direction to determine the effect of these various changes on the economic study result (Canada et al., 1995). This analysis mainly uses tabulated relative sensitivity as shown in Table 1 for representation (Sullivan et al., 2002).

	Annual Expenses, E								
	O			M			P		
	Useful Life, N			Useful Life, N			Useful Life, N		
Annual Revenues, R	O	M	P	O	M	P	O	M	P
Optimistic (O)	[74]	[68]	[64]	[51]	45	41	37	31	27
Most Likely (M)	34	28	24	11	5	1	-3	-9	-13
Pessimistic (P)	14	8	4	-9	-15	-19	-23	-29	-33

Note.
AWs in $000s
O is optimistic outcome
M is most likely outcome
P is pessimistic outcome
[ ] indecates net annual worth > $50,000
Underscore indecates net anuual worth < 0

Table 1 Tabulated Relative Sensitivity for Optimistic-Pessimistic Analysis
(Source: Sullivan et al., 2002, 464)

Graphical display for optimistic-pessimistic sensitivity analysis is presented by using two-dimensional bar chart as shown in Table 1 (Canada et al., 1995). Table 1 shows two-dimensional histogram bars for all combinations of estimating conditions—optimistic (O), most likely (M), and pessimistic (P)—for three cash flow elements. The heights of the bars represent the values of the economic measure of merit. Regarding to

Canada et al. (1995), other devices such as color coding, shading, etc., can be very useful for communicating in terms of tables and graphs.

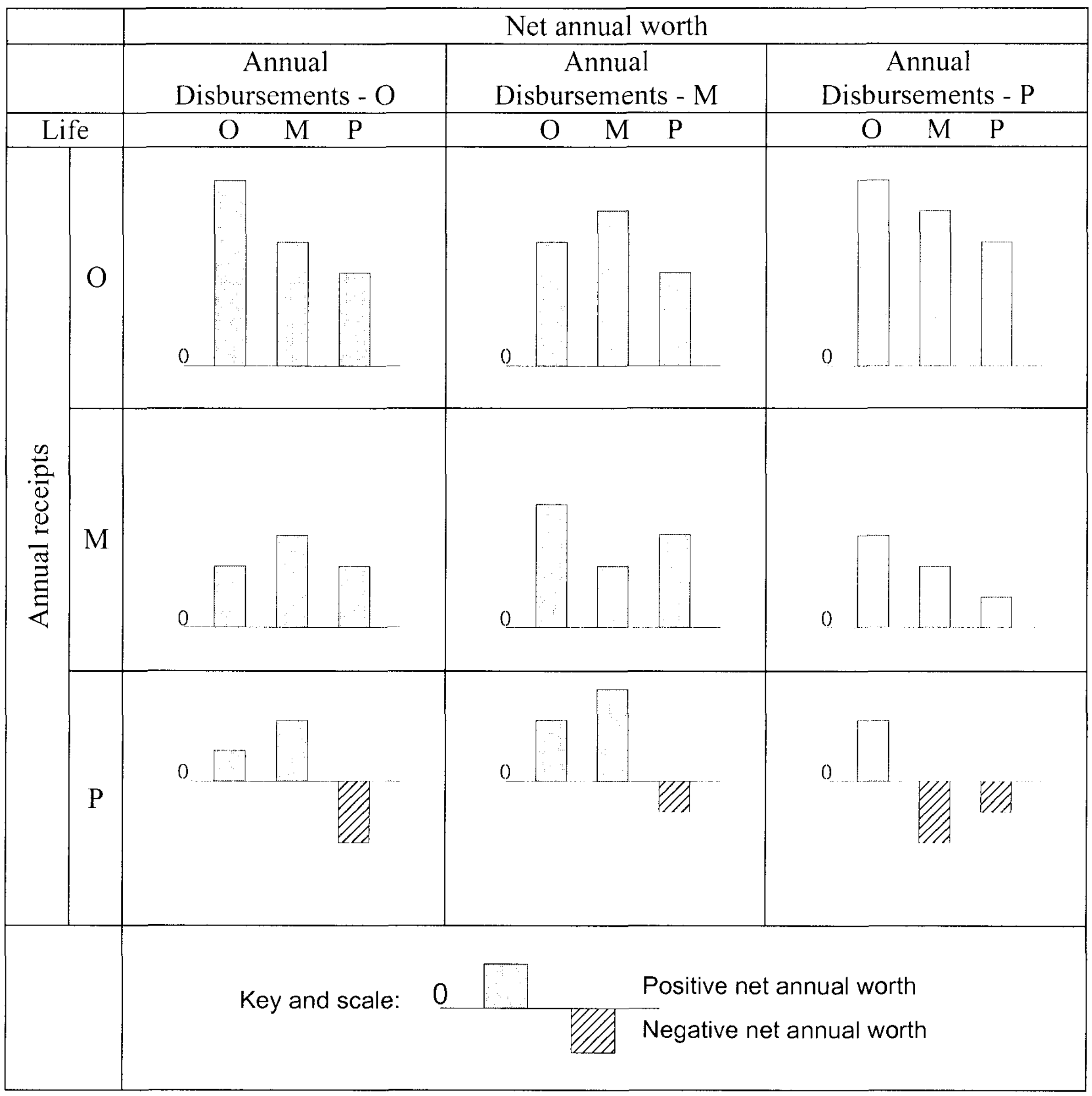


Figure 11 Graphical display for Optimistic-pessimistic Sensitivity Analysis (Adapted from Canada et al., 1995, 301)

Sensitivity analysis for the combined effects of three cash flow elements can adapt the approach used in optimistic-pessimistic sensitivity analysis but it will suffer from two major defects. One of the major weaknesses of optimistic-pessimistic sensitivity analysis is it cannot capture the combined effects of small incremental changes on each cash flow element. Another weakness is the number of graphs or calculations required grows exponentially as the number of interesting cash flow elements increases arithmetically (Fleischer, 1994). These two defects make performing sensitivity analysis or understanding of information more difficult for decision makers. Table 2 shows an example of tabulated relative sensitivity analysis for the combined effects of three cash flow elements with $\pm 40\%$ percent deviation from based case or most likely on each cash flow element.

% of A (-40% to 40%)

	-40%				
	% of N (-40% to 40%)				
% of I (-40% to 40%)	-40%	-20%	0%	20%	40%
-40%	-1	0	2	3	3
-20%	-3	-2	-1	0	1
0%	-6	-4	-3	-2	-1
20%	-8	-7	-5	-4	-3
40%	-10	-9	-8	-7	-6

	-20%				
	% of N (-40% to 40%)				
% of I (-40% to 40%)	-40%	-20%	0%	20%	40%
-40%	1	3	4	6	7
-20%	-2	0	2	3	4
0%	-4	-2	0	1	2
20%	-6	-4	-3	-1	0
40%	-8	-7	-5	-4	-2

	0%				
	% of N (-40% to 40%)				
% of I (-40% to 40%)	-40%	-20%	0%	20%	40%
-40%	3	5	7	8	10
-20%	0	2	4	6	8
0%	-2	0	2	4	5
20%	-4	-2	0	2	3
40%	-7	-4	-2	-1	1

	20%				
	% of N (-40% to 40%)				
% of I (-40% to 40%)	-40%	-20%	0%	20%	40%
-40%	4	7	9	11	13
-20%	2	5	7	9	11
0%	0	2	5	7	9
20%	-3	0	2	5	8
40%	-5	-2	0	2	4

	40%				
	% of N (-40% to 40%)				
% of I (-40% to 40%)	-40%	-20%	0%	20%	40%
-40%	6	9	12	14	17
-20%	4	7	10	12	14
0%	1	5	7	10	12
20%	-1	2	5	8	10
40%	-3	0	3	5	7

Table 2 Tabulated Relative Sensitivity Analysis for the Combined Effects of Three Cash Flow Elements

Figure 12 shows an example of graphical display of sensitivity analysis for the combined effects of three cash flow elements based on optimistic-pessimistic sensitivity analysis approach.

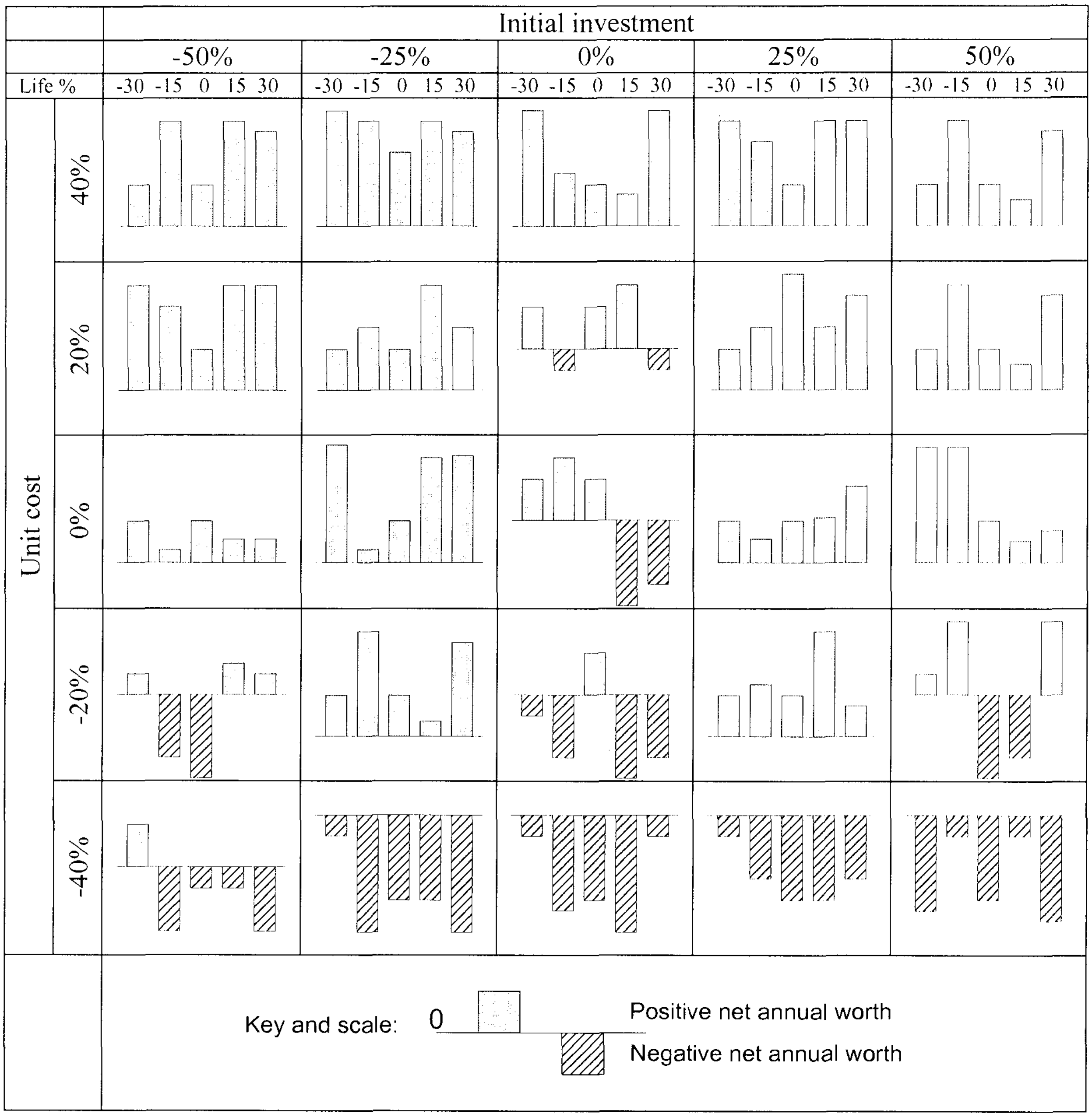


Figure 12 Graphical Display of Sensitivity Analysis for the Combined Effects of Three Cash Flow Elements.

Twenty engineering economic texts have been explored to summarize and group the texts, coverage of sensitivity analysis. For comparison purposes Table 3 has been divided into three categories of sensitivity analysis in engineering economy: One-at-a-time analysis, the combined effects of two cash flow elements, and the combined effects of three cash flow elements. The table was further divided into graphical and non-graphical displays presented each sensitivity analysis category. The table also includes whether the texts cover the importance of interactions among cash flow elements. These interactions among cash flow elements are fundamental in the combined effects of two or more cash flow element sensitivity analysis. In some cases the texts explicitly support, present, or mention, while in others a judgment needed to be made by the reader.

Authors & Edition	Copy Right	One-at-a-time analysis		Interaction among cash flow elements	Two-at-a-time analysis		Three-at-a-time analysis	
		Non-graphical	Graphical		Non-graphical	Graphical	Non-graphical	Graphical
Blank & Tarquin, 5th	(2002)	✔	✔					
Bowman	(2003)	✔	✔					
Bussey & Eschenbach	(1992)	✔	✔	✔	✔		✔	
Canada, Sullivan, & White, 2nd	(1995)	✔	✔	✔	✔	✔	✔ [a]	✔ [b]
Collier, & Glagola	(1998)	✔						
Eschenbach, 2nd	(2003)	✔	✔	✔	✔	✔		
Fisher	(1971)	✔	✔	✔	✔			
Fleischer	(1992)	✔	✔	✔	✔	✔		
Fleischer	(1994)	✔	✔	✔	✔	✔	✔	
Grant, Ireson, & Leavenworth	(1990)	✔						
Newnan, Lavelle, & Eschenbach, 8th	(2002)	✔	✔					
Ostwald & McLaren	(2004)	✔	✔					
Park & Sharp-Bette	(1990)	✔						
Park, 3rd	(2001)	✔	✔	✔				
Steiner	(1996)	✔	✔	✔				
Sullivan, Bontadelli, & Wicks, 11th	(2000)	✔	✔	✔	✔	✔	✔ [a]	
Sullivan, Wicks, & Luxhoj, 12th	(2002)	✔	✔	✔	✔	✔	✔ [a]	
Thuesen & Fabrycky, 9th	(2000)	✔	✔					
White, Case, Pratt, & Agee	(1998)	✔	✔	✔	✔	✔		
Young	(1993)	✔	✔	✔	✔			

Note.

✔ Indicates supporting, presenting, or mentioning in the texts

[a] Presenting in scenario analysis table

[b] Presenting in scenario analysis with graphical bar chart

Table 3 Summary of Text Positions for Sensitivity Analysis

Related Sensitivity Analysis Techniques in Engineering Economy

Other related major sensitivity analysis techniques in engineering economy are the simulation and artificial neural network (ANN) with metamodel approaches. "A metamodel is a simplified or approximated descriptive model of another descriptive model" (Chaveesuk & Smith, 2003, 2). Simulation provides a flexible means to test the sensitivity of the weights or alternatives of an engineering economy problem. There is engineering economy related software that was based on these simulation concepts such as @Risk from Palisade (2003). According Badiru and Sieger (1998), the simulation approach has many benefits such as increasing the decision maker's understanding of the general characteristics of behavior of the system under study (sensitivity analysis and what-if analysis), predicting the values of an output (response) variable, performing optimization of the system, and verifying and validating a model.

According to Chaveesuk and Smith (2003), using artificial neural network (ANN) with metamodel approach for sensitivity analysis has many important aspects such as ANN is difficult to properly construct and validate, requiring a knowledgeable user and specialized software, the generalization ability of an ANN must be thoroughly tested, the interpretation of both prediction and significant factors is difficult and less rigorous, and ANN will require a large data set to achieve high accuracy.

Those two approaches are difficult to properly construct and validate and they require a knowledgeable user and specialized software. They need a large data set to achieve high accuracy. The interpretations of both approaches require a knowledgeable user comparing to graphic display approaches.

Relevant Visual Graphical Display Research

The relevant visual graphical display literature will be presented using a matrix with display characteristics being represented on the matrix's axes. According to Dryer (1996), visual displays can be characterized by three general factors, a display's visual configuration, visual perspective, and study intent.

Display Perspective

The first classification of graphical display research is display perspective. It consists of two major classifications: two-dimensional and three-dimensional graphical display perspective. According to Morris (1976), a definition for two-dimensional perspective is a display that has only two dimensions, length and width, portraying visual information in a planar fashion. A definition for three-dimensional perspective is a display that exists in three dimensions and has, or appears to have, extension in depth, thus portraying information in a volumetric fashion. Figure 13 shows examples of two-dimensional and three-dimensional graphical displays.

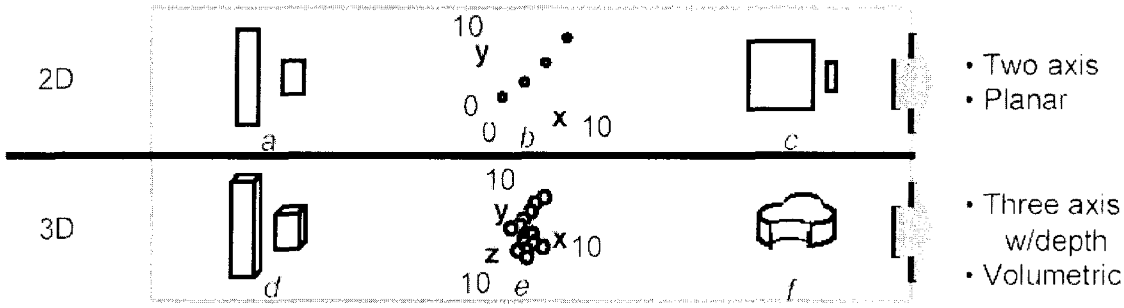


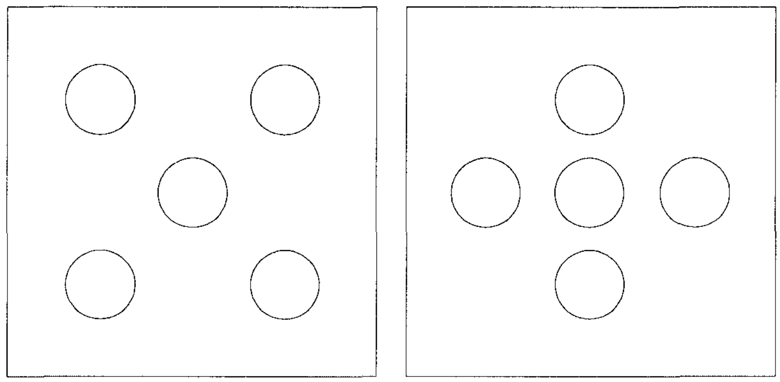
Figure 13 Display Perspective
(Source: Dryer, 1996, 10)

The purpose of a three-dimensional graphical display is not to replace a two-dimensional graphical display, but instead to allow the quantitative analysis to be more focused. According to Tegarden (1999, 9), the three-dimensional graphical display allows decision makers to "a) exploit the human visual system to extract information from data, b) provide an overview of complex data sets, c) identify structure, patterns, trends, anomalies, and relationships in a set of complex data, and d) assist in identifying the areas of interest." In other words, three-dimensional graphical displays allow decision makers to use their natural spatial and visual abilities to determine where further exploration should be done. They also assist the decision makers to get an overview picture of a data set at a glance. Another benefit of three-dimensional graphical displays is that they have the potential of high information density because large amounts of information can be viewed from one integral graphical display at a time.

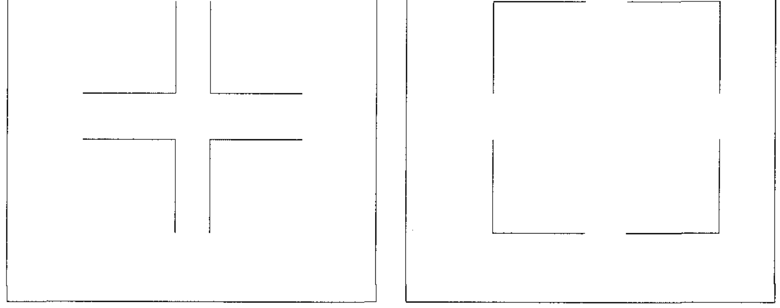
Display Configuration

The development of display configurations was related to the research area of stimulus interaction (i.e., perceptual differences based on varying combinations of dimensional changes in a stimulus set) (Pomerantz & Garner, 1973; Pomerantz & Sager, 1975). Display configuration could be divided into three configurations of graphical display (Dryer, 1996; Garner, 1978; Pomerantz & Pristach, 1989). The first configuration, Type P-Configuration, is display configuration defined by only position of elements. Figure 14 shows two groups of static stimulus sets to illustrate these configuration types. In the stimulus sets of Group A, the letter elements act as placeholders, whose positions indicate salient points on a unitary figure, as when a group of stars form a constellation.

The second configuration is Type N-Configuration. In this type, the nature of elements and also the position of elements define the configuration of display. As shown in Group B in Figure 14, changing the position and orientation of elements changes overall of display configuration. Besides Type P and Type N configurations, Pomerantz noted a third possible organization of elements in a visual field. In this case, elements can be perceived as independent, ungrouped, and belonging to different objects or figures. This display case lacks any configuration and is similar to Garner's category of separable stimulus sets and will be termed separable.



Type P-Configuration. Group A



Type N-Configuration. Group B

Figure 14 Type-P and Type-N Configuration
(Adapted from Dryer, 1996, 16)

Display Intent

The last characteristic of the graphical display research matrix is the general study purpose or intent of the display. The intent of a research domain's literature can be generally classified as basic or applied. With further investigation, applied graphical displays can also be classified into many areas and one of them is sensitivity analysis graphical display in engineering economy. In Figure 15, the basic level can be viewed as an outer shell, the applied level as a middle shell, and the sensitivity analysis graphical display in engineering economy level as the inner core.

Relevant literature is also assessed using the visual graphical display research matrix. This structure portrays the portion of the human computer interaction, visualization, and sensitivity analysis in engineering economy body of knowledge relevant to graphical information processing display as shown in Figure 15.

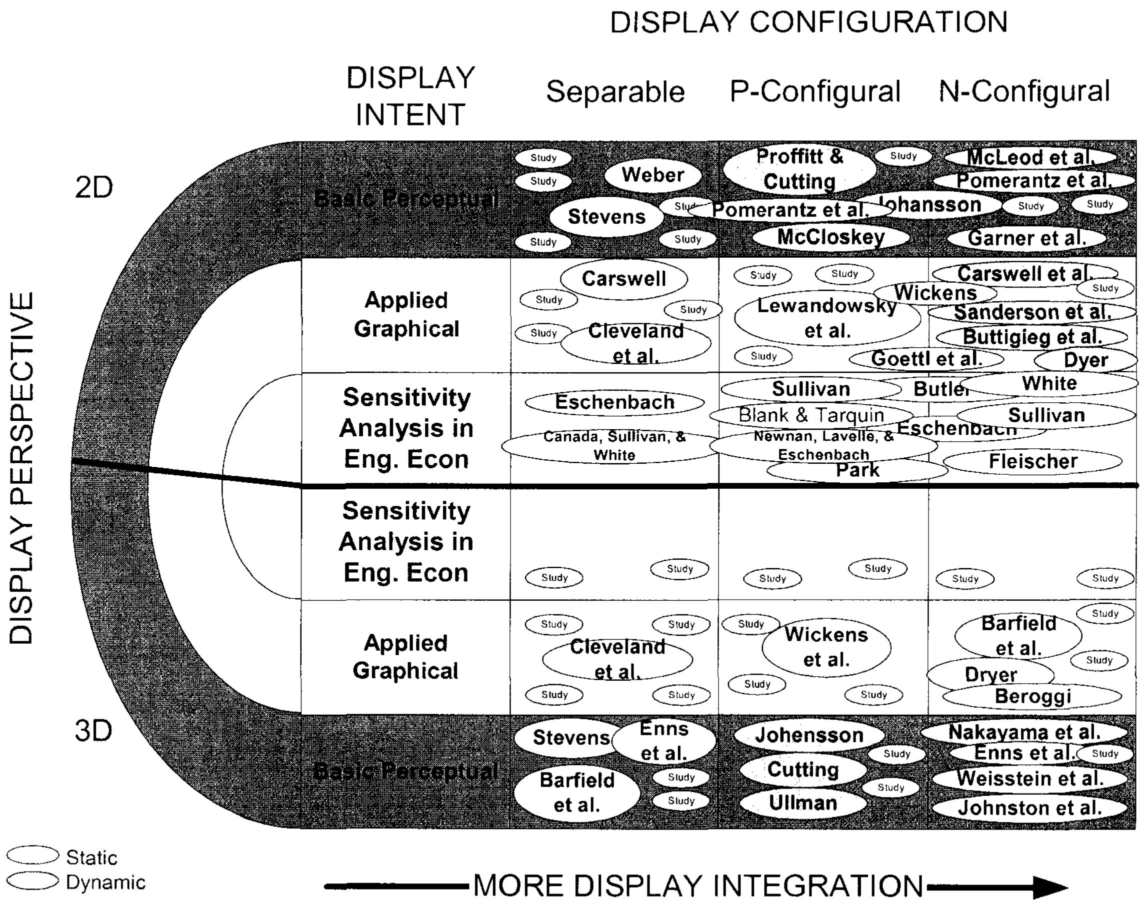


Figure 15 Gap in the Body of Knowledge

(Adapted from Dryer, 1996, 26)

Integral and Separable Displays

According to Eschenbach (2003), one of the limitations of one-at-a-time sensitivity analysis graphical displays (i.e., break-even chart, spiderplot) is the difficulty to display many cash flow elements in one display. This limitation can lead to benefits of integral displays over separable displays.

Garner (1970) described integral dimensions as those that produce redundancy gains and interference effects in speeded classification tasks and separable dimensions as exhibiting neither of these effects. Typically, integral dimensions are perceived holistically (i.e., as a single object), whereas separable dimensions are perceived as separable entities (Jones & Wickens, 1990). For example, a sensitivity analysis display of the combined effects of two cash flow elements similar to Figure 8 could be considered as an integral display, whereas the displays in Figure 3 would be called separable display. Performance on simple judgment and classification tasks is improved when completely redundant dimensions are displayed in an integral manner (Garner, 1969; Garner, 1970; Garner & Fefoldy, 1970; Lockhead, 1966).

Goldsmith and Schvaneveldt (1984), forwarded by Jones and Wickens (1990, 2), in their investigation on integral displays and separable displays concluded that "the integration and use of multiple sources of information can be facilitated be presenting information cues in a display configuration with integral dimensions." Similarly, Carswell and Wickens (1987) founded that the integral dimensions of a integral display led to improved performance in a simple process monitoring task. There were further investigations summarized by Wickens (1986) that the object display (integral display) advantage was increased by the degree of integration that a task requires. Sensitivity analysis of the combined effects of three or more cash flow elements would be considered as a task that requires a high degree of integration compared to one-at-a-time sensitivity analysis. Therefore, an integral display concept would be an appropriate approach for sensitivity analysis of the combined effects of three cash flow elements.

Color in Graphical Information Displays

Since many of the pitfalls of visualization revolve around color perception, to truly make the most use out of the visualization of technical data, color must be well understood (Fortner & Meyer, 1996). According to Tufte (1990), there are strategies for how color can serve information. Pure, bright or very strong colors have loud, unbearable effects when they stand unrelieved over large areas adjacent to each other, but extraordinary effects can be achieved when they are used sparingly on or between dull background tones. The placing of light, bright colors mixed with white next to each other usually produces unpleasant results, especially if the colors are used for large area. Large area background or base-colors should do their work most quietly, allowing the smaller, bright areas to stand out most vividly, if the background is muted, grayish or neutral.

Color has been used in many fields of visualization for many years. It is excellent for labeling and categorization (or nominal tasks) (Mackinlay, 1999; Ware, 2000). Quantitative data can also be encoded by color. One of the promising techniques of using color to encoded quantitative data is pseudocoloring or color scales technique.

Preattentive processing refers to an initial organization of the visual field based on cognitive operations believed to be rapid, automatic, and spatially parallel. Color is well accepted as a preattentive feature especially for high-speed target detection, boundary identification, and region detection. In sensitivity analysis for an engineering project, a decision maker always has to identify sensitive cash flow elements and acceptable range of variation of those cash flow elements. Table 4 lists two-dimensional visual features that have been used to perform preattentive tasks (Healey, Booth, & Enns, 1998).

Humans can efficiently search for a target color among various distracter colors "as long as the target and distracter colors are not too similar or close in color space" (De Valois, 2000, 345). There are promising results of using color in visualization in many areas of research such as molecular modeling, medical imaging, brain structure and function visualization, mathematics, geosciences, meteorology, space exploration visualization, astrophysics, computational fluid dynamics visualization, and finite element analysis (DeFanti, Brown, & McCormick, 1989).

Feature	Author
Line (blob) orientation	(Julesz & Bergen, 1983; Wolfe, Friedman-Hill, Steward, & O'Connel, 1992)
Length	(Triesman & Gormican, 1988)
Width	(Julesz, 1984)
Size	(Triesman & Gelade, 1980)
Curvature	(Triesman & Gormican, 1988)
Number	(Julesz, 1984; Trick & Pylyshyn, 1994)
Terminators	(Julesz & Bergen, 1983)
Intersection	(Julesz & Bergen, 1983)
Closure	(Triesman & Souther, 1986)
Color (hue)	(D'Zmura, 1991; Nagy & Sanchez, 1990; Triesman & Gormican, 1988)
Intensity	(Beck, Prazdny, & Rosenfeld, 1983; Triesman & Gormican, 1988)
Flicker	(Julesz, 1971)
Direction of motion	(Driver, McLeod, & Dienes, 1992; Nakayama & Silverman, 1986)
Binocular luster	(Wolfe & Franzel, 1988)
Stereoscopic depth	(Nakayama & Silverman, 1986)
3D depth cues	(Enns, 1990)
Lighting direction	(Enns, 1990)

Table 4 A List of Two-Dimensional Preattentive Features in Visual Search

(Source: Healey et al., 1998, 112)

Even though color is very useful in visualization researchers must be aware that around 9 percent of population has some sort of color deficiency. As Hsia and Graham (1965, 395) state that:

"... color deficiency individuals may be classified as dichromats, monochromat, or anomalous trichromats. Dichromats are individuals who match any color of the spectrum with an appropriate combination of two primaries. Frequently the combinations of colors are such that one of the primaries is combined with the color to be matched. In other cased (e.g., tritanopes) the color to be matched is compared with the mixture of the two primaries. Monochromats match any color of the spectrum with any other color of the spectrum or a white. They cannot discriminate differences in hue.

Anomalous trichromats can, like color-normal persons, combine a light of spectrum with one of three primaries so as to match a mixture of the two remaining primaries. However, the respective amounts of the primaries required for the match are different from those required by the normal trichromat...The forms of dichromatism that occur most frequently are protanopia and deuteranopia or red blindness and green blindness respectively. The third type, tritanopia, occurs much less frequently than the other two."

Many more men than women have defective color vision. Approximately 8 percent of men are color defective, but less than 1 percent of women (Hsia & Graham, 1965). It is usually caused by a lack of either a red or green cone system (Fortner & Meyer, 1996).

Color Measurement and Color System in Graphical Displays

Color measurement is based on the theory of colorimetry. Any color can be matched or reproduced with a mixture of no more than three lights (usually called primaries) is the basis of colorimetry. Any color can be described by the following equation:

$$C \equiv rR + gG + bB$$

where C is the color to be matched, R, G, and B are the primary sources to be used to create a match, and r, g, and b represent the amounts of each primary light. The $\equiv$ symbol is used to denote a perceptual match (Ware, 2000). Figure 16 graphically illustrates this concept, where the axes of a three-dimensional space are the three primary colors (B, R, and G). Every color can be represented by a point in that space, by matching a certain amount of primary color *R*, an amount of primary color *G*, and some amount of primary color *B* (Levine & Shefner, 1991).

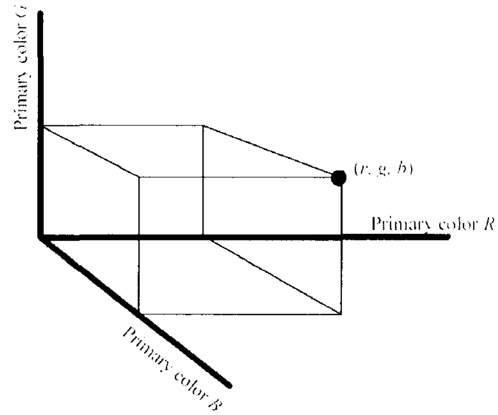


Figure 16 The Three-dimensional Space Formed by Three Primary Lights (Source: Levine & Shefner, 1991)

Based on the colorimetry, color systems can be developed. One of the most widely used color systems is Commission Internationale de L'Ĕclairage (CIE) system of color standard. The CIE system based on the standard observer is by far the most widely used standard for measuring colored light (Ware, 2000).

A color computer monitor is a light-emitting device with three primaries *RGB*. The red, green, and blue primaries are formed be the phosphor colors of a color computer monitor; this defines the gamut of the monitor. In general, a gamut is the set of all colors that can be produced by a device or sensed by a receptor system. It is relatively straightforward to use CIE system with RGB primaries to define color on color computer monitor (Fortner & Meyer, 1996). Therefore any color in experiments will be defined by the amount of *r, g,* and *b* in *RGB* color model (Figure 16). By this way, further color replication or reproduction based on the findings of this research can be accomplished correctly.

All information displays of one-at-a-time, two-at-a-time, and three-at-a-time sensitivity analysis are constructed based on two-dimensional information displays (Canada et al., 1995; Eschenbach, 1992; Eschenbach & McKeague, 1989; Fleischer, 1994; Park, 2001; Sullivan et al., 2002). Since three-at-a-time sensitivity analysis required extensive information displayed at the same time. This increased information complexity is harder to represent in conventional two-dimensional displays creating the need for display innovations that support the sensitivity analysis tasks of exploration, understanding, and decision making. Information visualization along with human computer interaction principle and theories were used to develop the three-dimensional information display. The study compared two-dimensional and three-dimensional representations of the same information, to determine if three-dimensional display benefits the user. The primary objective of the study was to examine whether the three-dimensional information display help decision makers' understanding of the combined effects of three cash flow elements in an engineering economy analysis

CHAPTER III

RESEARCH METHODOLOGY

According to Blank and Tarquin (2002), the general methodology for one-at-a-time sensitivity analysis is:

1. Determine which cash flow element(s) of interest might vary from the most likely estimated value.
2. Select the probable range and an increment of variation for each cash flow element.
3. Select the measure of worth.
4. Compute the results for each cash flow element, using the measure of worth as a basis.
5. To better interpret the sensitivity, graphically display the cash flow element versus the measure of worth.

Blank and Tarquin (2002)'s methodology did not give the decision makers criteria or how to choose cash flow elements. On the other hand, Eschenbach (2003), stated these criteria clearly in his methodology as shown below. By following Blank and Tarquin (2002)'s methodology, decision maker needs to construct a tabulated relative sensitivity analysis as shown in Table 5.

F(x)	X_1	X_2	X_3	...	X_n
Base Case	Base Case	Base Case	Base Case	Base Case	Base Case
$F(x)_1$	**Change**	Fix	Fix	Fix	Fix
$F(x)_2$	Fix	**Change**	Fix	Fix	Fix
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
$F(x)_n$	Fix	Fix	Fix	Fix	**Change**

Table 5 Tabulated Sensitivity Analysis for One-at-a-time Analysis

F(x) is a selected economic measure of merit and $X_1, X_2, \ldots X_n$ are interested cash flow elements. Usually, a spiderplot will be used as the graphical display for this kind of analysis. The methodology for constructing tabulated sensitivity analysis for the combined effects of three cash flow elements will be an extension of current one-at-a-time analysis methodology. The methodology is:

1. Determine which cash flow elements of interest might vary from the most likely estimated value. There are several possible criteria in choosing (1) the most important cash flow elements, (2) logically linked (such as inflation rates, prices, and quantity sold), and (3) the ones with the most uncertainty (Eschenbach, 2003).
2. Optionally, Decision makers can perform a Taguchi-Based analysis to determine which cash flow elements those are likely to be sensitive to the decision models. Phadke (1989), Unal, Stanley, and Joyner (1993), as well as other authors, outline the process of performing Taguchi's method.
3. Select the probable range and an increment of variation for each cash flow element.

4. Select the measure of worth.
5. Compute the results for all possible cash flow element variation combinations, using the measure of worth as a basis.
6. To better interpret the sensitivity, graphically display (using the proposed three-dimensional graphical display) the cash flow element and the measure of worth.

By following this procedure, tabulated relative sensitivity can be constructed as shown in Table 6.

F(x)	X_1	X_2	X_3	...	X_n
Base Case	Base Case	Base Case	Base Case	Base Case	Base Case
$F(x)_1$	**Change**	**Change**	**Change**	Fix	Fix
$F(x)_2$	Fix	**Change**	**Change**	**Change**	Fix
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
$F(x)_n$	Fix	Fix	**Change**	**Change**	**Change**

Table 6 Tabulated Sensitivity Analysis for Three-at-a-time Analysis

F(x) is a selected economic measure of merit and $X_1, X_2, \ldots X_n$ are interested cash flow elements.

Pseudocoloring

Pseudocoloring is one of the techniques of continuous representation of varying quantitative values using sequence of colors. In the pseudocolor imaging or technique, the maximum amount of information can be presented in the smallest space (Fortner & Meyer, 1996). Pseudocoloring is widely used for astronomical visualization, medical imaging, finite element analysis, and many other scientific applications (DeFanti et al., 1989).

In pseudocoloring, the values of a variable and also spatial change of that variable are represented. So a change in the hue that represents the variable should be proportional to the corresponding change in the underlying variable. One of the most widely used pseudocolor sequence is the rainbow or visible-light spectrum sequence. According to Ware (2000) and Fortner and Meyer (1996), the whole spectrum is not perceptually ordered. Cleveland and McGill (1983) and Ware (1988) have shown that errors resulting from simultaneous color and brightness contract can be quite large when using visible-light spectrum in pseudocoloring. When there is no requirement for high levels of detail in data and a perceptually orderable sequence is required, some chromatic sequence or saturation sequence can be used, i.e., black-white (gray scale), red-green, yellow-blue (Rogowitz & Treinish, 1996).

Although color is an excellent information coding attribute especially in ordinal and nominal related tasks (Mackinlay, 1999), only a small number of codes can be rapidly perceived. According to Healey (1996), five to ten codes can be rapidly perceived. These approximate numbers are quite close to human short-term memory limitation, which is seven plus or minus two (Miller, 1956).

Accuracy ranking of quantitative, ordinal, and nominal perceptual tasks

People accomplish the perceptual tasks associated with the interpretation of graphical presentations with different degrees of accuracy (Cleveland & McGill, 1984). Cleveland and McGill (1984) focused on the presentation of quantitative information. They identified and ranked the tasks shown in Figure 17. Higher tasks are accomplished more accurately than lower tasks. Furthermore, they have some experimental evidence that supports the basic properties of this ranking. Cleveland's taxonomy of specifiers (Carswell, 1992) and representative graphical format is shown in Table 7.

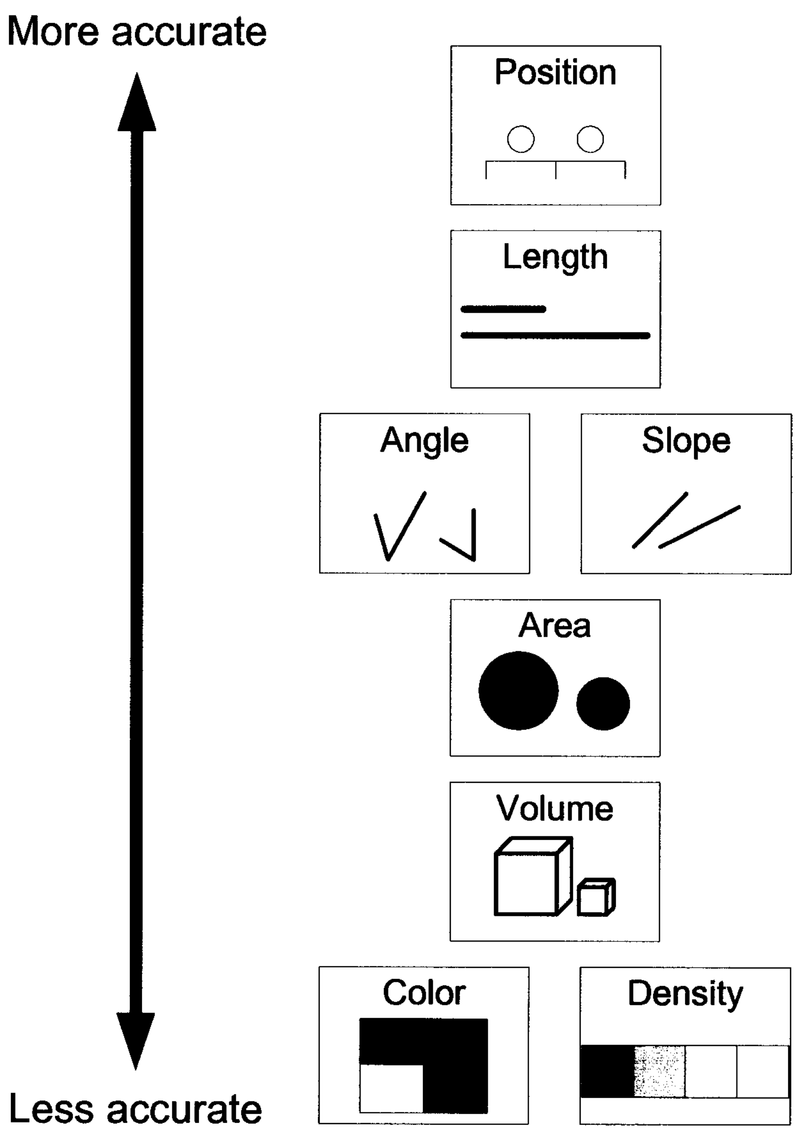


Figure 17 Cleveland's Accuracy Ranking
(Source: Mackinlay, 1999, 73)

Specifier	Representative Graphical Formats
Position on common aligned scale	Line graphs, bar charts (horizontal and vertical), univariate dot charts and point plots, many types of pictographs, histograms, profiles, bars with decorative depth
Position on common nonaligned scales	Polygon displays (stars, polar plots) with reference axes, bivariate point plots, scatter plots, statistical maps with framed rectangles
Length	Polygon displays (star, polar plots) without reference axes, hanging histograms, segmented bar charts, trees, castles
Angle/Slope area	Pie charts, disk, meters Circles, blobs, some pictographs
Volume/ density/ color saturation	Cubes, some pictographs, statistical maps with shading, luminance-coded displays
Color hue	Statistical maps with color coding

Table 7 Specifier and Representative Graphical Format

(Adapted from Carswell, 1992)

Although the ranking in Figure 17 can be used to compare alternative graphical languages that encode quantitative information, it does not address the encoding of nonquantitative information, which involves additional perceptual tasks and different task rankings. There are many preattentive features that are not mentioned in Cleveland's ranking such as texture, shape, and color, which is at the bottom of the quantitative ranking. Ware and Beatty (1985) argued that color is a very effective way of encoding nominal sets. Therefore, it was necessary to extend Cleveland and McGill's ranking, as shown in Figure 17. "Although this extension was developed using existing psychophysical results and various analyses of the different perceptual tasks, it has not been empirically verified". Table 8 shows taxonomy lists types of specifiers ordered from most to least accurately use (Mackinlay, 1999, 73).

More accurate ↑ … ↓ Less accurate	Quantitative	Ordinal	Nominal
More accurate	Position	Position	Position
	Length	Density	Color Hue
	Angle	Color Saturation	Texture
	Slope	Color Hue	Connection
	Area	Texture	Containment
	Volume	Connection	Density
	Density	Containment	Color Saturation
	Color Saturation	Length	Shape
	Color Hue	Angle	Length
	Texture	Slope	Angle
	Connection	Area	Slope
	Containment	Volume	Area
Less accurate	Shape	Shape	Volume

Table 8 Ranking of Perceptual Tasks

(Adapted from Mackinlay, 1999, 73)

Color scales

According to Levkowitz and Herman (1992), a proper color scale that can contribute to the perception of information in graphical displays should have the following properties: a) order, b) uniformity and representative distance, and c) boundaries. According to Levkowitz and Herman (1992, 72-73), they state:

"Given a sequence of numerical values $\{ v_1 \leq ... \leq v_N \}$ represented by the colors $\{ c_1,...,c_N \}$ respectively, the color sequence should have:

Order. The colors used to represent the values in the scales should be perceived as preserving the order of the values. The relationship among the colors should be

$$c_1 \text{ perceived-as-preceding} \ldots c_i \ldots \text{ perceived-as-preceding } c_N$$

...Uniformity and representative distance. The colors scales should convey the distances between the values they represent. Colors representing values equally different from each other along the scales should be perceived as equally different. That is, for any $1 \le i, j, m, n \le N$, if $v_i - v_j = v_m - v_n$, then the color scales should have $pd(c_i, c_j) = pd(c_m, c_n)$, where $pd(c, c')$ is the perceived distance between c and c'. Important differences in the values should be represented by colors clearly perceived as different, while close values should be represented by colors perceived to be close to each other...

Boundaries. The color scale should not create perceived boundaries that do not exist in the continuous numerical data..."

In this research, Present Worth (PW) values were encoded by color. So the used color scale should allow the decision makers to perceive the change of PW values from negative to positive uniformly.

With a proper color scale, there are many benefits in graphical display both theoretical considerations and practical issues. According to Robertson (1988, 53), the benefits are such as intuitive addressability, uniformity, independent control of lightness and chromatic contrast, and basis for complex perceptual data descriptions.

As aforementioned, any color in this experiment was specified by using color c = (r, g, b) in which r, g, and b are integers between 0 and 255 (Figure 18 and Figure 19).

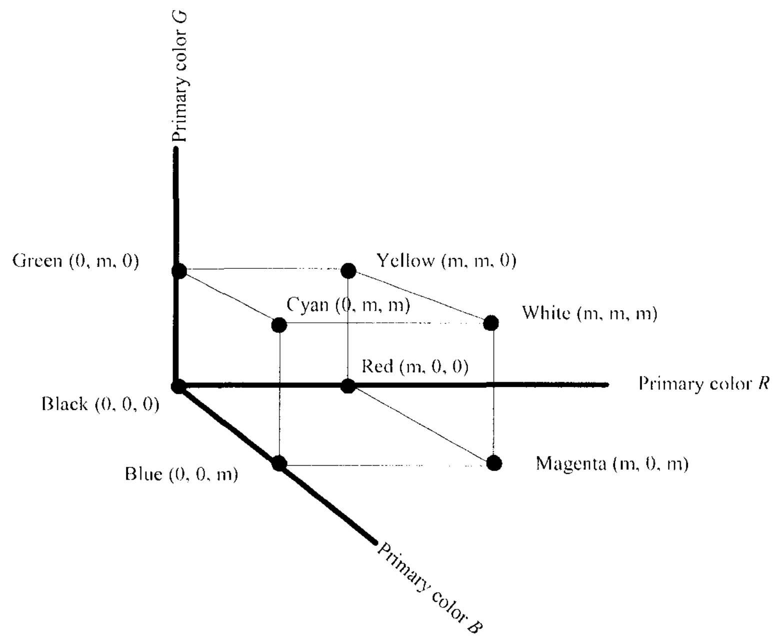


Figure 18 Color c = (r, g, b) in Which r, g, and b Are Integers Between 0 and M (Adapted from Levine & Shefner, 1991)

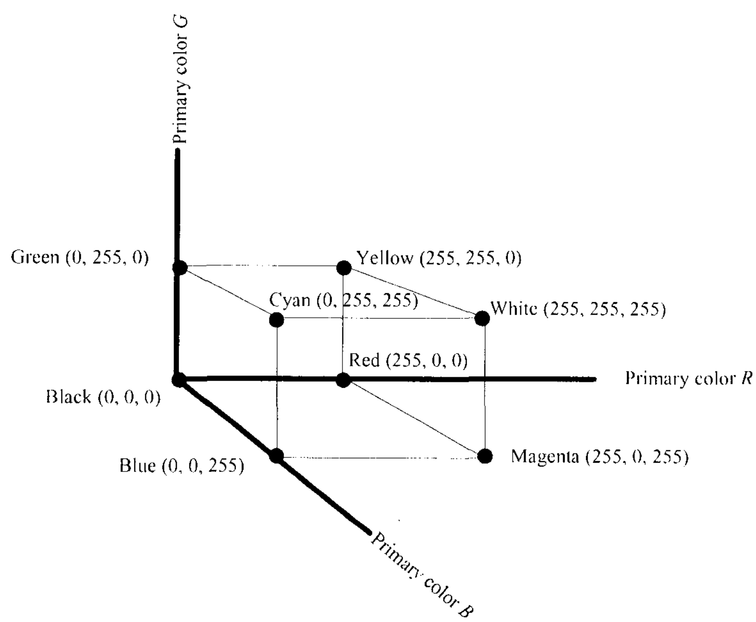


Figure 19 On a Typical Computer Monitor, M is equal to 255 (Adapted from Levine & Shefner, 1991)

Commonly Used Color Scale

According to Levkowitz (1997), the most commonly used color scale is the gray scale. While not considered a color scheme, it is the result of traversing the color solid along the achromatic axis. This can be implemented by keeping equal intensities for the three primaries red, green, and blue (R, G, B) and increasing them monotonically from 0 to M (M = 255 for typical computer monitor).

The rainbow scale or spectrum scale is another widely used color scale in geographical and physical information display (Fortner & Meyer, 1996; Ware, 2000). This scale can be implemented by traversing the color solid along a path from black to white, passing through all the hues of the rainbow (Red, Orange, Yellow, Green, Blue, Indigo, Violet), though at different lightnesses.

Another two widely used color scales are Heated-Object scale and Magenta scale. Both scales are based on the claim that natural color scales seem to be produced when the intensity of the three primary colors red, green, and blue rise monotonically and with the same order of magnitude of intensities throughout the entire scale (Levkowitz, 1997; Pizer, Zimmerman, & Johnston, 1982). The Heated-Object scale is implemented by increasing the gun intensities in the order red, green, and blue. It is based on the fact that the human visual system has maximum sensitivity to luminance changes for the orange-yellow hue. The Magenta scale is implemented by increasing the gun intensities in the order red, blue, and green. It is based on the fact that the human visual system is most sensitive to hue changes for the magenta hue.

Beside those three color scales, there are widely used color scale such as Blue-to-Cyan, Optimal Color Scale, Linear Optimal Color Scale, Blue-to-Yellow, Linear Gray Scale, Red-Green, Saturation scale, and Linear Rainbow.

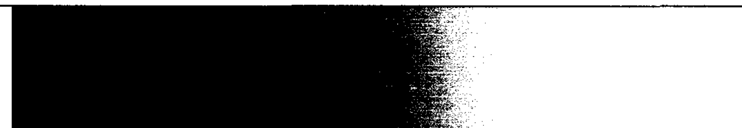
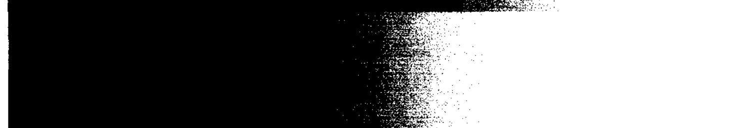
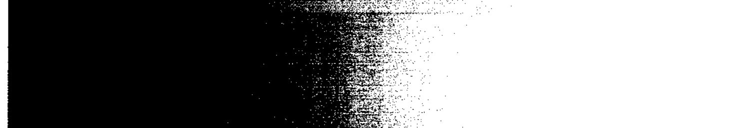
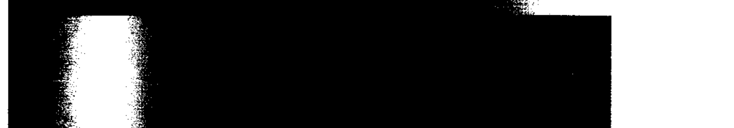
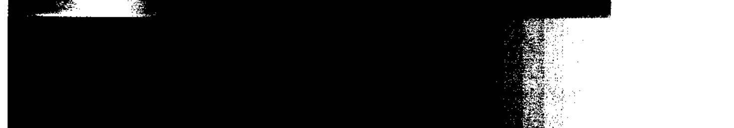
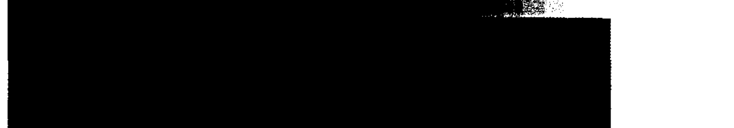
Magenta	
Blue-to-Cyan	
Gray	
Blue-to-Yellow	
Heated-Object	
Linear Gray	
Rainbow	
Green saturation scale	
Red-Green scale	
Linear Rainbow	
Optimal Color Scale	
Liner Optimal Color Scale	

Table 9 Widely Used Color Scales
(Source: Levkowitz, 1997; Ware, 2000)

According to Levkowitz and Herman (1992), there are at least 256 colors in a color scale to be perceived continuously. Therefore to generate a new color scale, at least 256 colors need to be generated. A color can be specified by using color c = (r, g, b) in which r, g, and b are integers between 0 and 255 (for a typical computer monitor). The newly developed color scale for this experiment was based on two main color hues. The main purpose of two color hues is to clearly distinguish between positive and negative values of the measure of merit (i.e., PW) used in an engineering project. Magenta and the Orange-Yellow hue will be used as the two main hues. This is based on the fact that the human visual system having maximum sensitivity to luminance changes for the orange-yellow hue and it is most sensitive to hue changes for the magenta hue (Levkowitz, 1997; Levkowitz & Herman, 1992). In this research, a new magenta color scale was developed based on original magenta color scale, as shown in Figure 20, by linearly reducing from 256 colors to 128 colors as shown in Figure 21.

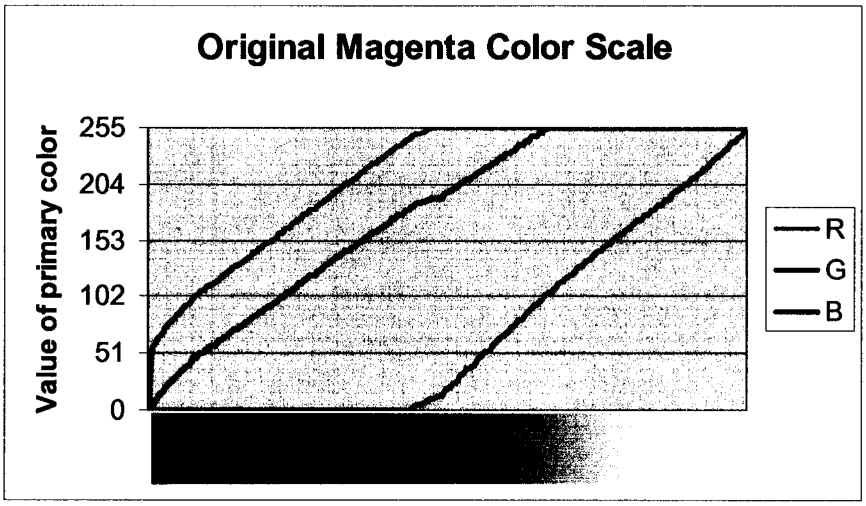


Figure 20 Magenta Color Scale
(Source: Levkowitz, 1997)

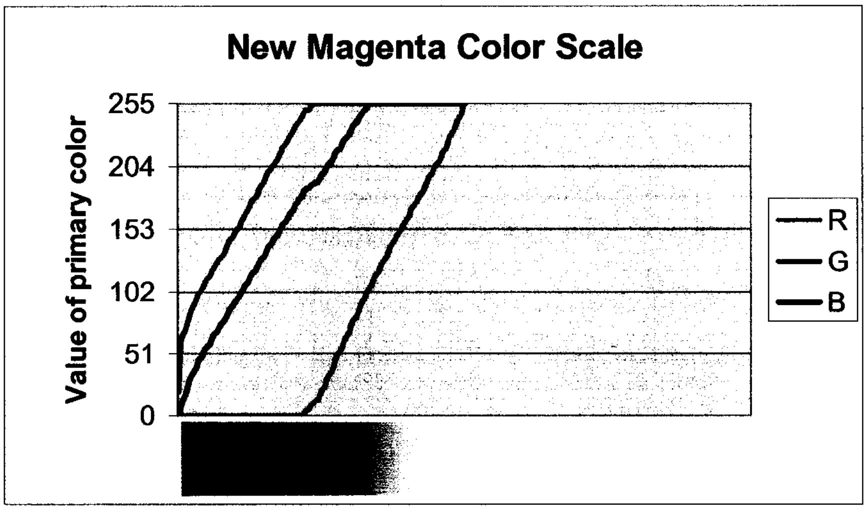


Figure 21 Reduced Magenta Color Scale

The Orange-Yellow hues can be implemented by using the same intensity as the Magenta color scale but in a different order. Instead of using red, blue, and green, the Orange-Yellow color scale was using red, green, and blue. The intensity used in the Orange-Yellow color scale was different form the Heated-Object color scale. After getting 256 colors of the Orange-Yellow color scale, a linearly reduction to 128 colors was implemented. Then the new color scale was implemented by combining the reduced Magenta color scale and the reduced Orange-Yellow color scale. Figure 22 and Figure 23 show the original Orange-Yellow and the reduced Orange-Yellow color scale respectively.

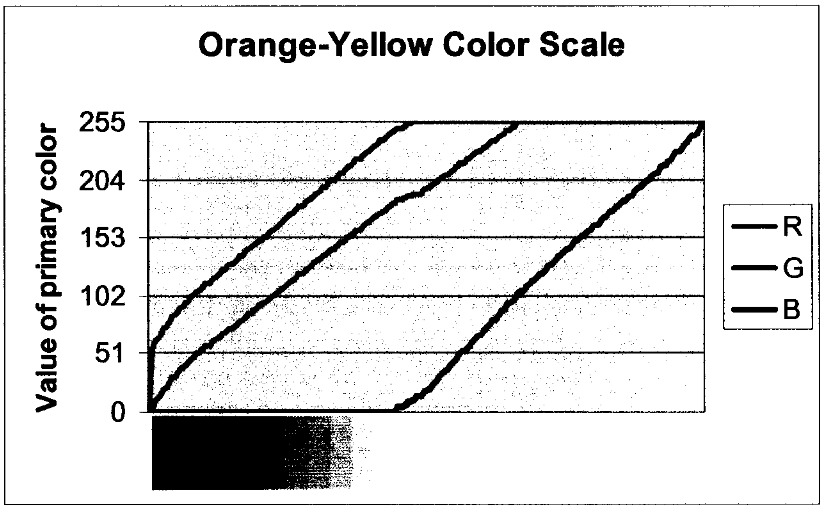


Figure 22 Orange-Yellow Color Scale

(Source: Levkowitz, 1997)

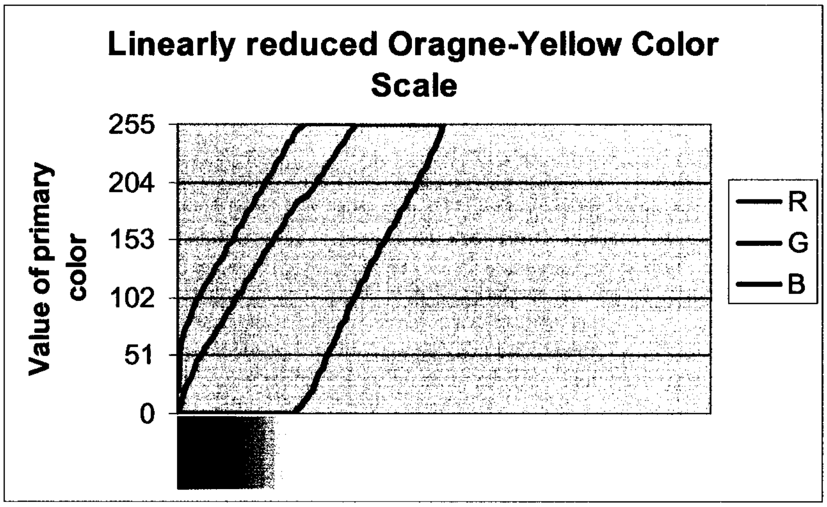


Figure 23 Reduced Orange-Yellow Color Scale

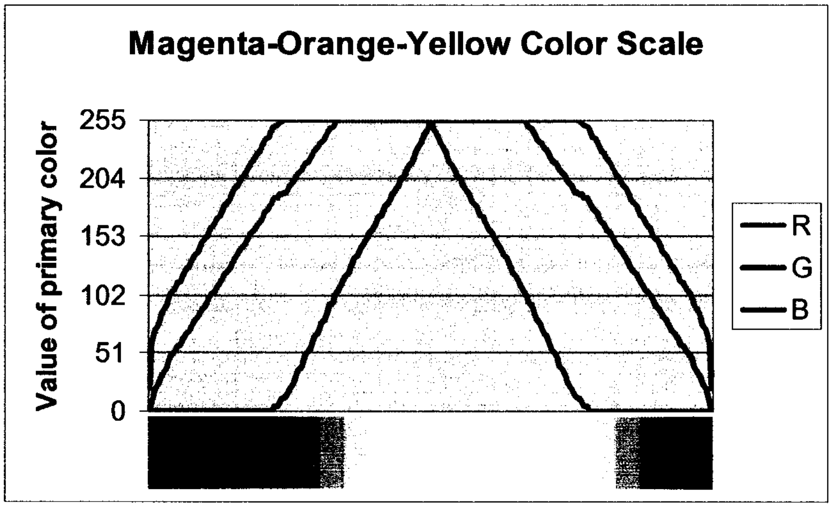


Figure 24 Magenta-Orange-Yellow Color Scale

The values of the measure of merit (i.e., PW) were mapped to the new Magenta-Orange-Yellow scale, as shown in Figure 24. The negative values were mapped to the magenta scale section and the positive values were mapped to the Orange-Yellow scale section. The color scale was presented in the three-dimensional graphical display used in the experiment. Providing the color scale in the graphical display assists the users in assessing the different aspects of the color scale communicated different characteristics of the data (Rogowitz & Treinish, 1996). Figure 25 shows an example of PW mapped to Magenta-Orange-Yellow color scale.

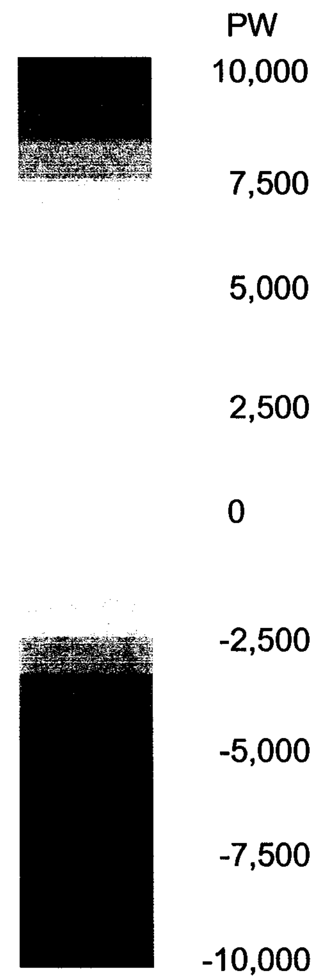


Figure 25 An Example of PW Mapped to Magenta-Orange-Yellow Color Scale

Pilot Study

The pilot tests were designed to validate the experimental displays and the experimental protocol. As aforementioned, the color scale used in the pilot study was Magenta-Orange-Yellow color scale. The think aloud protocol also revealed that the participants were distracted by both the Orange-Yellow color scale (for positive PW) and the magenta color scale (for negative PW) (Barnum, 2002). It also revealed that the participants confused when using two color scales at the same time.

This problem was presented in the literature in infrared satellite imaging areas (Arnold & Meyer, 2004). The problem can be overcome by using one color scale along with a gray scale (Bader, Forbes, Grant, Lilley, & Waters, 1995; Ritchie et al., 2003; Wilhelmson & Ramamurthy, 2003). The color scale makes locations or areas with the desired values (negative PW) easier to locate. For this reason, the Magenta-Gray color scale was used instead of Magenta-Orange-Yellow color scale. Figure 26 presents an example of PW mapped to Magenta-Gray color scale.

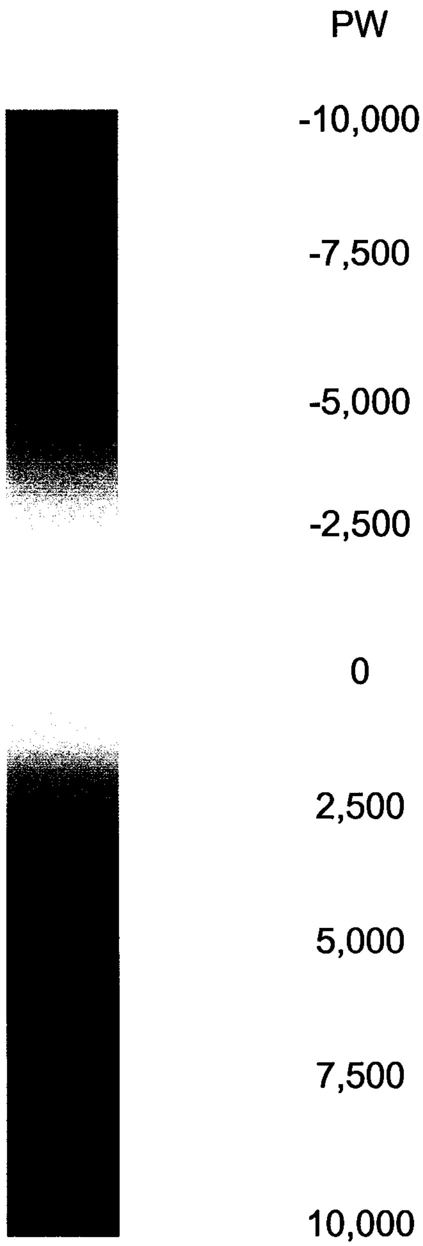


Figure 26 An Example of PW Mapped to Magenta-Gray Color Scale

CHAPTER IV

RESEARCH DESIGN

This chapter discusses the type of experimental design, participants, apparatus, experimental tasks, experimental procedure, and experimental environment. This section of the experimental effort will produce quantitative results useful in deriving meaningful conclusions and recommendations concerning specific displays features. Now the specifics of the experimental parameters and design are discussed.

A between-subject design was used. The between-subject design is characterized by the fact that participants are randomly assigned to, and serve in only one of, the different treatment conditions. Although it is not necessary, an equal number of participants are usually assigned to each treatment group. Between-subject designs are simpler to understand conceptually, are easier to design and to analyze, and are relatively free from restrictive statistical assumptions. The main disadvantages are the large number of participants required for even a modest experiment and a relative lack of sensitivity in detecting treatment effects or practice effects when they are present (Keppel, 1991).

According to Whitley (2002), researchers use within subject designs much less frequently than between-subjects designs. This less frequent use results from a set of disadvantages inherent in within-subjects designs referred to collectively as order effects. An order effect occurs when participants' scores on the dependent variable are affected by the order in which they experience the condition of the independent variable. Practice effects are differences on the dependent variable that result from repeatedly performing the experimental task. Usually participants will change systematically during the course of multiple testing. Participants may show a general improvement during the course of testing, in which case the practice effect is positive; alternatively, fatigue or boredom may build up on the successive tests to produce a negative practice effect. Carryover effects occur when the effect of one condition of the experiment carries over to and affects participants' performance in another condition. Sensitization effects are a form of reactivity: experiencing one condition of the experiment affects their performance in the other condition. Moreover, between-subject experimental designs are common in information display studies (Dryer, 1996; Maxwell & Delaney, 1990) because, as mentioned, they are less susceptible to problems of differential carryover or an excessive number of trials for each subject that might occur with a completely within-subjects design (Maxwell & Delaney, 1990). Other procedures using within-subject designs have been prone to order and carryover effects thus jeopardizing the external validity of the results (Carswell & Wickens, 1987).

The display configuration independent variable was manipulated. Besides the independent variables, participants' background information and after session opinion were collected. Figure 27 and Figure 28 show examples of the sensitivity bar chart display (2D) and the three-dimensional display (3D) for sensitivity analysis for the combined effects of three cash flow elements that were used in this study respectively.

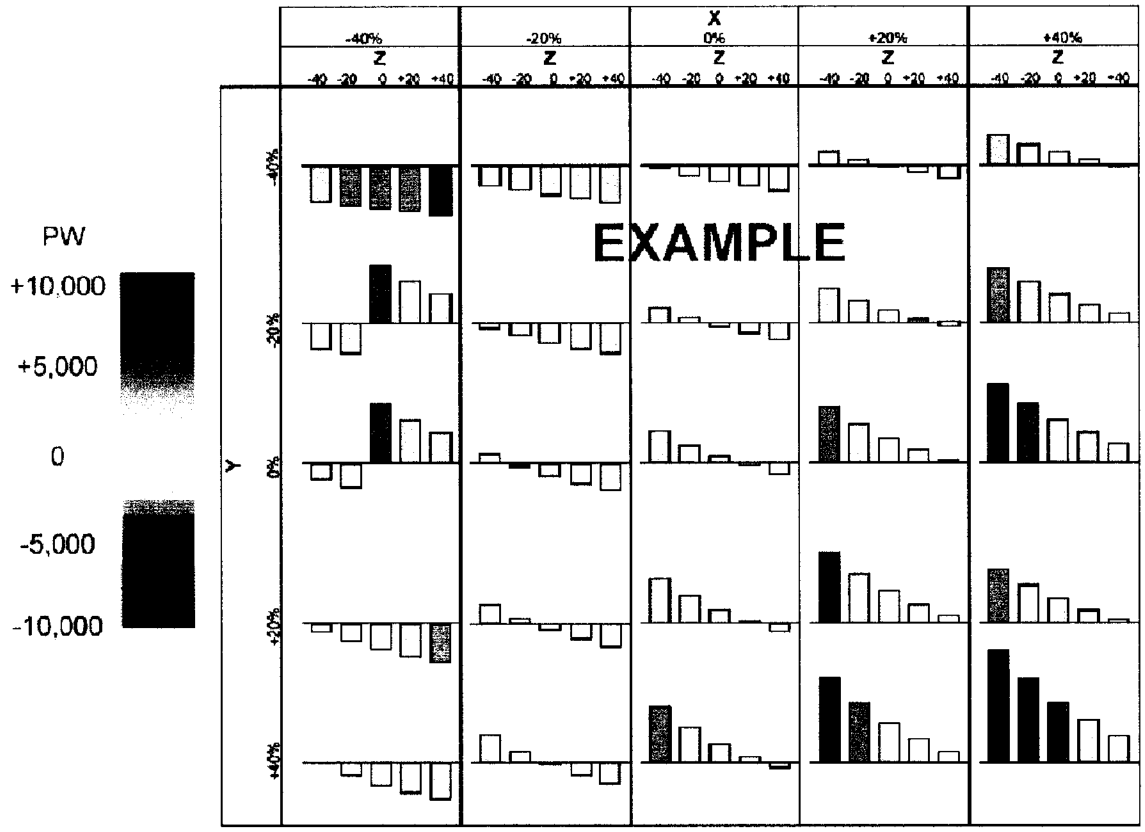


Figure 27 An Example of Sensitivity Bar Chart Display

The dependent variables in this study were accuracy and latency. Concerning accuracy, participants were asked to identify a magnitude of selected cash flow element and a relationship of the combined effects of three selected cash flow elements. If the participant changed the answers during the experiment, the last answers would be collected as final answers.

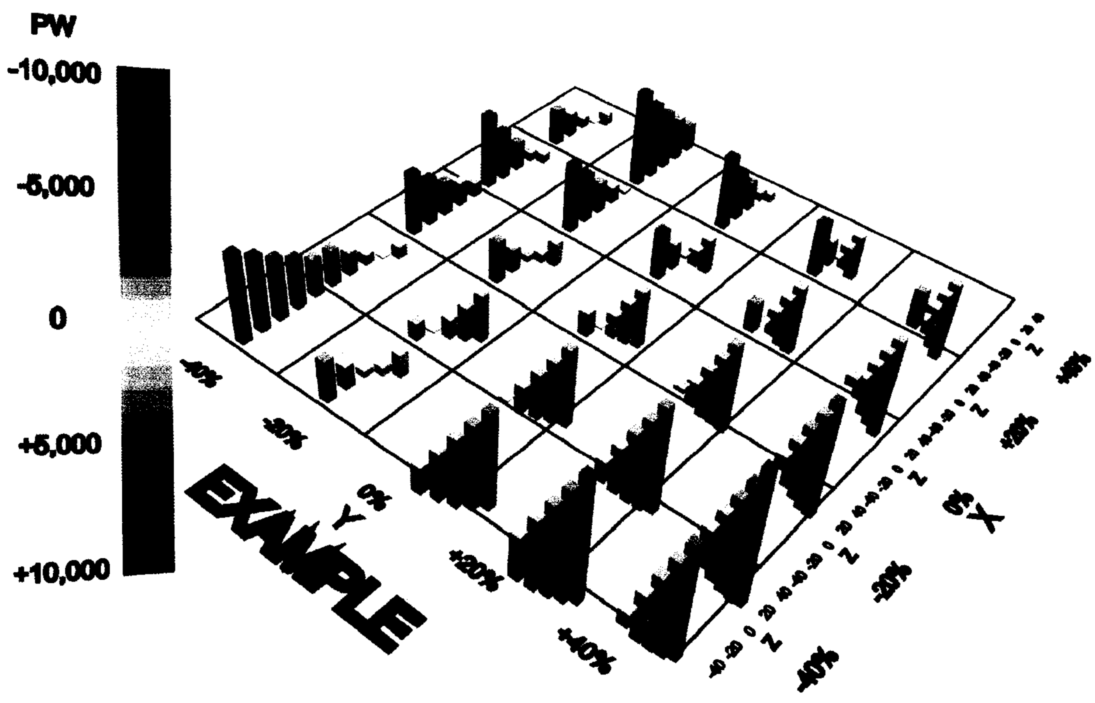


Figure 28 An Example of Three-dimensional Graphical Display

Concerning latency, a response time was recorded for each task, which was the time from when the experimenter finished the question, until the subject finished giving a response.

Participants

The participants were 36 Old Dominion University graduate students enrolled in the Engineering Management and System Engineering Department. Based on estimated sample size table prepared by Bratcher, Moran, and Zimmer (1970), with two-level design, $\alpha = .05$, and $1 - \beta = .80$, the minimum required participants are 17 per experiment group. That gives a statistical power equal to .80, which is preferred in most experiments (Kirk, 1982). The participants volunteered to participate in this experiment and were rewarded by extra credit in a class (ENMA 600) as determined by the instructor. The extra credit (3 points) was fixed for each participant. It was not varied by participants' performance. An additional incentive for good performance in experiment was a monetary price ($10) for the best performance. The participants had to be able to see the computer display correctly. Therefore, if the participants normally wear eyeglasses or contact lenses, they will need to wear them to participate. Participants were randomly assigned to either the sensitivity bar chart condition or the three-dimensional display condition (Whitley, 2002). This study was approved by Old Dominion University's Human Subjects Review Board and the experimenter had completed the "Human Participants Protection Education for Research Teams" online course, sponsored by the National Institute of Health (NIH).

Apparatus

An IBM Pentium IV 1.2 GHz microcomputer with 128 MB RAM was used to present the displays. The color monitor screen was approximately 14 inches in diagonal, with a viewable resolution of 1024 x 768 pixels. The color monitor was calibrated (contrast, brightness, and color saturation) with Adobe Gamma (McClelland, 2000). Participants were seated in an experimental laboratory, isolated from noise and distractions. The maximum heights and widths of the displays were 21.5 cm x 28 cm for the sensitivity bar chart and the three-dimensional display. With a head position approximately 75 cm from the screen, these measurements subtend 16.3 x 21.1degrees of visual angle.

Experimental tasks

During the experiment, participants were asked to perform the following tasks:

- Based on the combined effects, if P (initial cost) changes by –20% from the base case, please identify the minimum values of A (annual benefit) and N (project life) that make this project become unacceptable.
- Based on the combined effects, describe the combined effects or joint effects of these three variables.

During the experimental phase, the participants were asked to use the "think aloud" technique – i.e., verbalize their thought process. The experimenter recorded an accuracy score and the latency of each participant in addition to these verbalized thoughts. After the experiment, participants were asked to complete the after session questionnaires in which they expressed their agreement or disagreement with statements on a five-point Likert scale. Likert scales are scales on which participants register their agreement or disagreement with a statement (Rubin, 1994). The Likert scale used had the following vales: 1 = "strongly disagree", 2 = "partly disagree", 3 = "neither agree nor disagree", 4 = "partly agree", and 5 = "strongly agree" (Barnum, 2002). The statements consist of:

- I found the display easy to understand the combined effects of three cash flow elements
- I consider the display help me to get better understanding of sensitivity analysis information
- I found the display easy to indicate reversal point or range
- From a managerial standpoint, the display helped me made better decision
- I found the display easy to extract information that I need
- I found the display stressful to use
- I found the display gave motivation to use

The second section of the after-session opinion questionnaire consists of three main open-ended questions:

- Did you have a strategy for extracting information from the display(s)? If so, what was it?
- What was the first information you looking for in the display for sensitivity analysis of the combined effects of three cash flow elements?
    - What was the strategy?
- Do you have any other thoughts, feelings, or comments about this experiment?

The complete after-session opinion questionnaire is listed in Appendix E and Appendix F. After that the participants were asked to view another type of display for example the participants in the 2D condition were asked to view the 3D display. The participants were asked to think aloud or verbalize their thought process that which display condition that they prefer and why (Barnum, 2002). Then the participants were asked to complete the second opinion questionnaire. The complete second opinion questionnaire is listed in Appendix G.

Procedure

Participants were randomly assigned to either the 2D (sensitivity bar chart) condition or the 3D (three-dimensional) condition. The detailed protocol for each condition is listed in Appendix D. First, the informed consent document was presented and verbally explained to each participant. Once participants understood and signed the informed consent document, they were asked to complete participants' background information questionnaire. Then the participants' instruction was presented and the pre-experimental phase began. During the pre-experimental phase lasting approximately 5 minutes, participants were shown the Ishihara color test plates and a spiderplot diagram. It is not necessary in all cases to use the entire set of images. In a large scale examination the test can be simplified to 6 tests; test 1, one of tests 2 or 3, one of tests 4, 5, 6 or 7, one of tests 8 or 9, one of tests 10, 11, 12 or 13 and one of tests 14 or 15 (Byrne, 2002). This study used test plates 1, 2, 4, 8, 10, and 14 (as shown in Appendix H).

The main experimental phase lasted approximately 10 minutes. During the main experimental phase, participants were asked to verbalize their thoughts or think aloud (Barnum, 2002). Getting the participants to think aloud is asking them to perform an unnatural act, so the experimenter would emphasize that he was very interested in understanding what the participant was thinking about when performing the experimental tasks. Then participants were asked to complete the after session opinion questionnaires as shown in Appendix E through Appendix G. Figure 29 shows the experimental procedure.

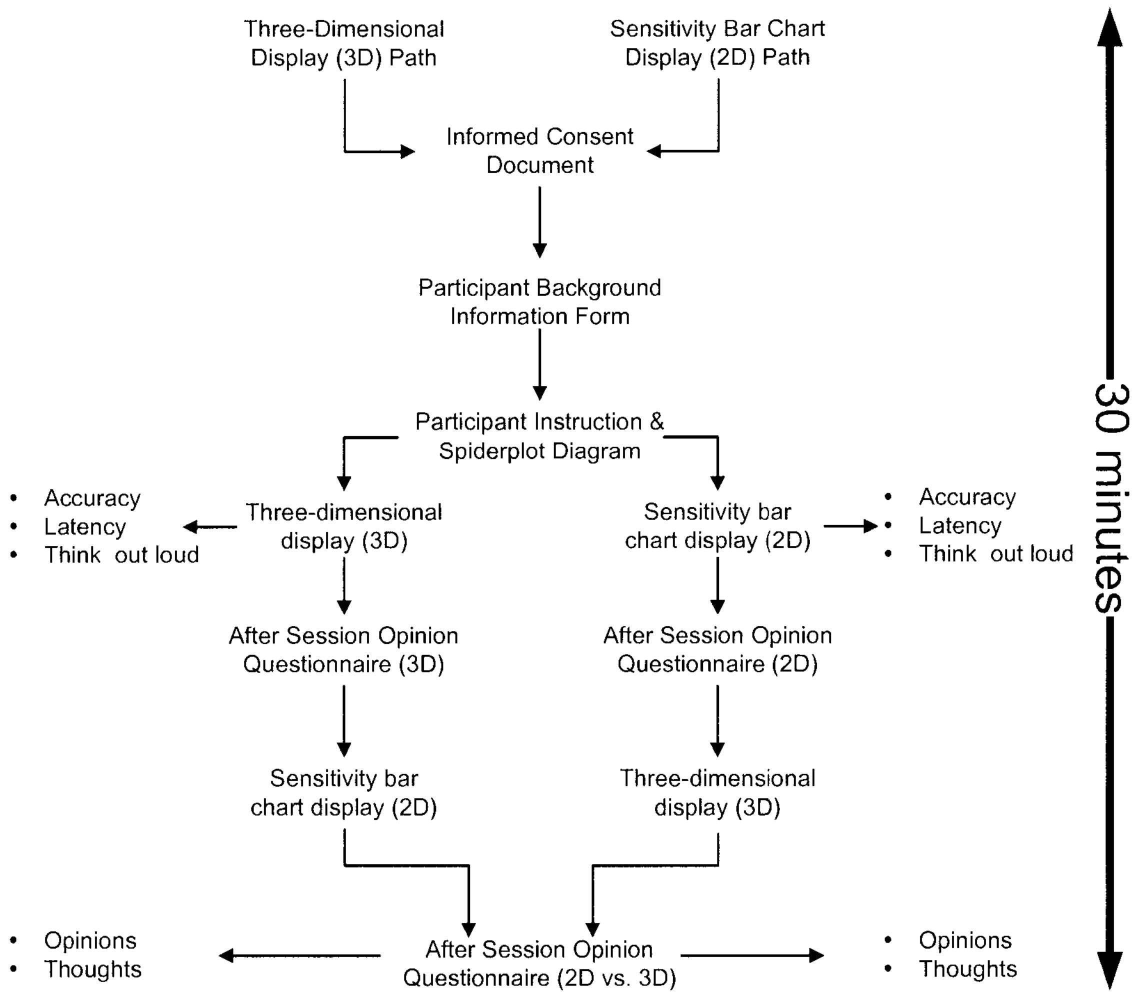


Figure 29 Experimental Procedure

Pre-Experimental Phase

Participants were tested for ability to perceive color used in the experiment. The Ishihara color deficiency test was used to provide a quick and accurate assessment of color vision deficiency. The original card version (by Dr. Shinobu Ishihara) was designed to be carried out in a room adequately lit by daylight. The presence of direct sunlight or artificial light may produce some discrepancy in the results because of some alteration in the appearance of shades of color. The electronic version may also produce some discrepancies as the images have been optimized for being displayed with a monitor resolution of 800x600 and 256 color display or greater (Byrne, 2002). The color monitor that was used in this study had a viewable resolution of 1024 x 768 pixels and it was set to display16 million colors.

Participants were positioned about 75cm from display monitor and were asked to read the numbers on of the image. During the experiment, the participants were asked to maintain their position about 75 cm from the display monitor by the experimenter. The test was simplified to 6 tests; test 1, 2, 4, 8, 10, and 14 (Byrne, 2002). Appendix H provides the color test plates.

Participants were presented a spiderplot diagram (as shown in Figure 30) to refresh their memory about one-at-a-time sensitivity analysis in engineering economy. Participants were explained the content of the spiderplot diagram and the limitations of spiderplot diagram when performing more-than-one-at-a-time sensitivity analysis.

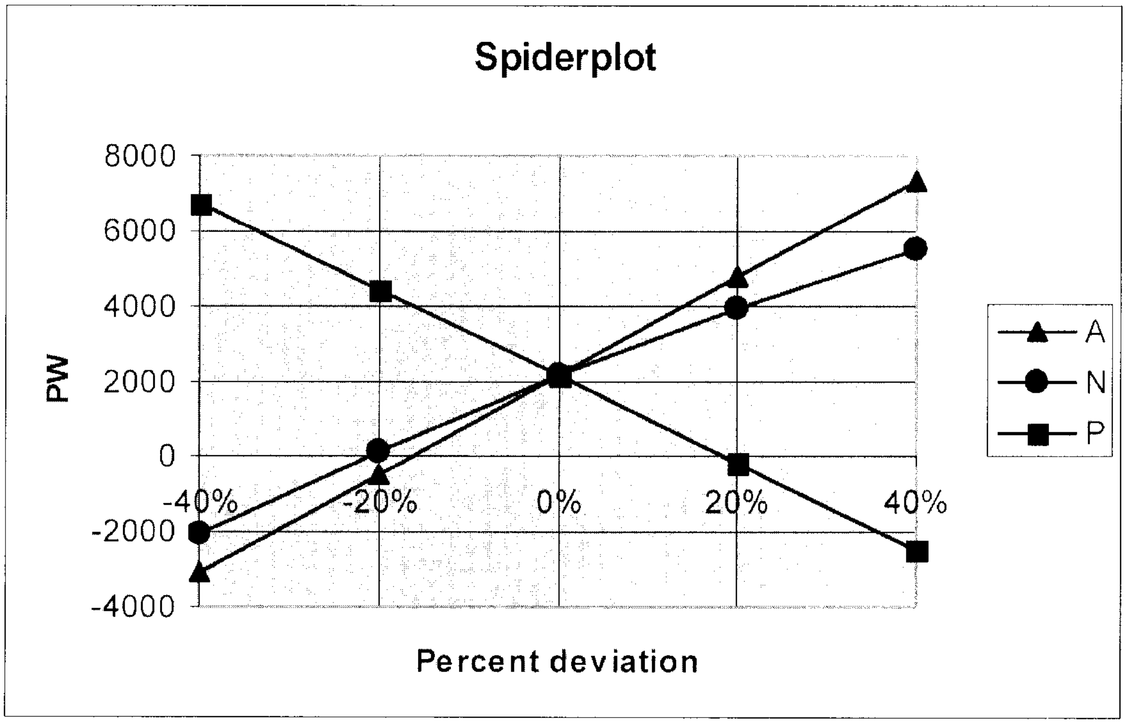


Figure 30 Spiderplot Diagram

Familiarization and practice phase

Participants were positioned about 75cm from the center of the display monitor. During the experiment, the participants were asked to maintain their position about 75 cm from the display monitor by the experimenter. An example of the experimental display (Figure 27 or Figure 28) was viewed and verbally explained by the experimenter from the written protocol, including the location of variables, descriptions of each variable, and the overall content of the display.

Experimental phase

Once participants were familiar with the experimental display, the experimental phase was conducted. The experimental display was presented and participants were verbally asked the questions for the tasks. The participants were asked to think aloud so the experimenter could record what they were thinking about when performing the experimental tasks. Once each question was read, the experimenter recorded accuracy, latency, and information from the think aloud technique. Once a response was given, immediate feedback was provided by the experimenter who responded with either "correct" or "incorrect, the answer is…." After the experiment, the participants were asked to complete an after-session questionnaire for the experimental display they used. The detailed questionnaire is listed in Appendix E. Then the participants were presented the other experimental display without performing the earlier experimental tasks. After that the participants were asked to complete the second after session opinion questionnaire, which is listed in Appendix G.

Experimental Environment

Participants were asked to seat in the experimenter's office, isolated from noise and distractions. The office has a cubical shape (176 cm in width, 167 cm in height, and 160 cm in depth) with high wall. Participants were seated 75 cm from the screen that is normal working distance (Genecin, 1998).

Result Analysis Design

The results of the accuracy scores, latency, and participants' satisfaction through Likert-scale type were compared between the two groupings. The student t-test with Bonferroni correction was used. All the data were analyzed using SPSS version 11.

Regarding the Likert-scale, there is a debate on measurement scales and statistics. According to Whitley (2002), there are some authorities who hold that one can only use statistics that are designed for a particular level of measurement. Other authorities, however, hold that there is no absolute relationship between level of measurement and statistics. Michell (1986) distinguished the representational, operational, and classical paradigms of measurement. He then concluded that the controversy over measurement scales and statistics is an issue within only one of the paradigms, the representational. In the representational theory, the numbers represent an empirical relational system, which is thought of as an objective structure existing quite independent of our operations. Numbers are used as a convenience and are, in principle, dispensible. This is not so, according to operationism. According to it numbers do not point beyond themselves to a scale-free realm. Rather the data on which measurement is based are inherently numerical. They are numerical because the operations involved produce numbers. Davision and Sharma (1988) supported that idea of using parametric statistics such as t or F statistics on ordinal scale such as the Likert scale when certain conditions met.

According to Shaffer (1995) and Weisstein (2003), the Bonferroni correction is a multiple-comparison correction used when several independent t-tests are being performed simultaneously (since while a given alpha value may be appropriate for each individual comparison, it is not for the set of all comparisons). "In order to avoid a lot of spurious positives, the alpha value needs to be lowered to account for the number of comparisons being performed" (Weisstein, 2003, 1).

The simplest and most conservative approach is the Bonferroni correction, which sets the alpha value for the entire set of n comparisons equal to α by taking the alpha value for each comparison equal to α / n. Explicitly, given n tests T_i for hypotheses $H_i\ (1 \leq i \leq n)$ under the assumption H_0 that all hypotheses H_i are false, and if the individual test critical values are $\leq \alpha / n$, then the experiment-wide critical value is $\leq \alpha$. In equation form, if

$$P(T_i \ passes \middle| H_0) \leq \frac{\alpha}{n}$$

for $1 \leq i \leq n$, then

$$P(some\, T_i \ passes | H_0) \leq \alpha,$$

which follows from Bonferroni's inequalities.

CHAPTER V

DATA ANALYSIS

Participants' Background Information

The participants were 36 Old Dominion University graduate students from Engineering Management and System Engineering Department. Table 10 presents the percentage of participants for each of the two conditions.

Condition	n	%
2D	18	50%
3D	18	50%
Total	36	100%

Table 10 Percentage of Participants for Each Condition

Participants' age	For All Participants		For Participants in the 2D Condition		For Participants in the 3D Condition	
	n	%	n	%	n	%
20-29	15	42%	9	50%	6	33%
30-39	14	39%	7	39%	7	39%
40-49	6	17%	2	11%	4	22%
50-59	1	3%	0	0%	1	6%
60-69	0	0%	0	0%	0	0%
70-79	0	0%	0	0%	0	0%
Total	36	100%	18	100%	18	100%

Table 11 Distribution of Participants' Age

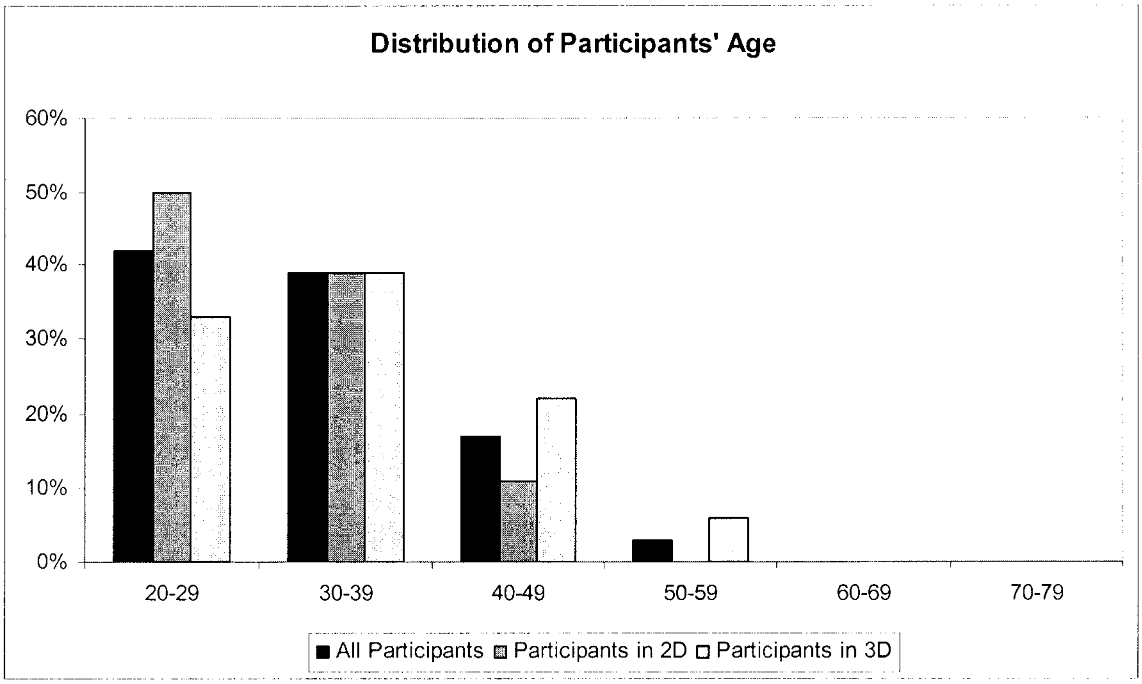


Figure 31 Distribution of Participants' Age

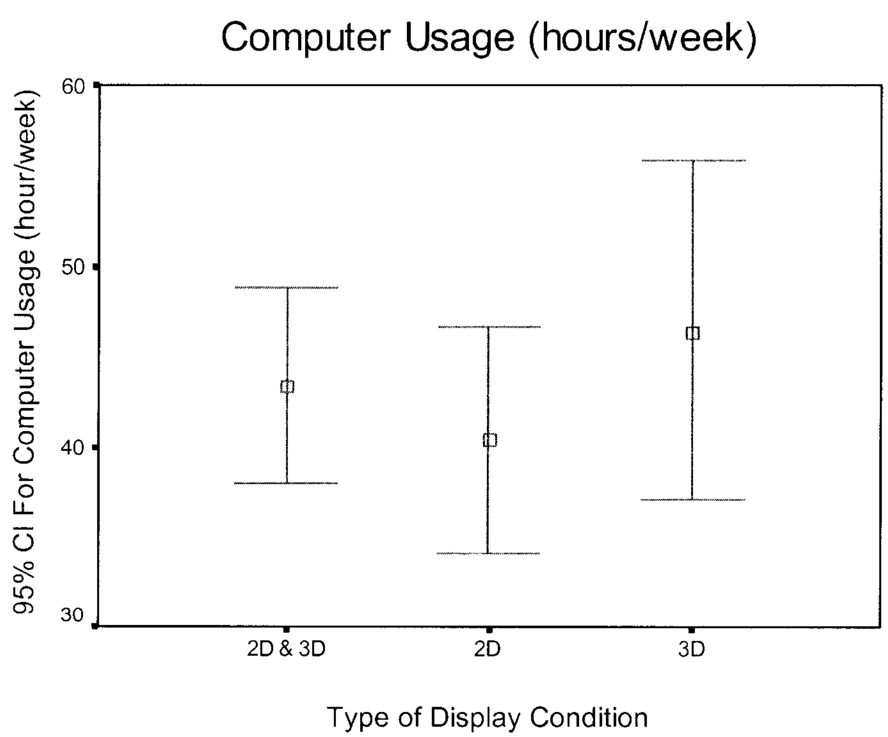


Figure 32 Participants' Background Information Question 3 Display by Error Bar Plot

Field of work	For All Participants		For Participants in the 2D Condition		For Participants in the 3D Condition	
	n	%	n	%	n	%
Full-time student	10	23%	5	22%	5	25%
Military officer	10	23%	6	26%	4	20%
Engineering manager or Project engineer	9	21%	4	17%	5	25%
Engineer	13	30%	8	35%	5	25%
Financial related	0	0%	0	0%	0	0%
Educational related	0	0%	0	0%	0	0%
Other	1	2%	0	0%	1	5%
Total	43	100%	23	100%	20	100%
Note. Participants may select all that applied						

Table 12 Participants' Field of Work

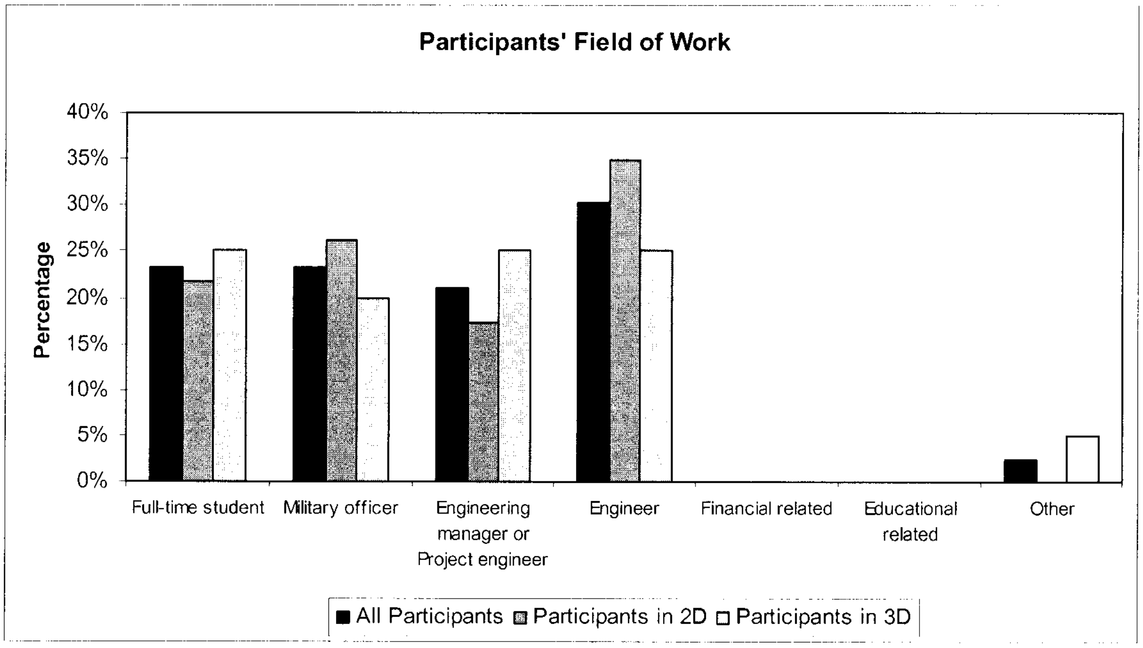


Figure 33 Participants' Field of Work Display by Bar Chart

Questions	For All Participants		For Participants in the 2D Condition		For Participants in the 3D Condition	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Years of working experience	10.78	7.95	9.00	6.64	12.56	8.91
Years of working experience related to engineering	6.94	7.18	6.50	6.82	7.39	7.70
Years of working experience at the management level	4.11	4.54	2.72	3.63	5.50	5.02

Table 13 Summary of Participants' Working Experiences

Concerning participants' background information, there were no significant differences between those in the 2D and 3D conditions. Participants' age ranged from 20-29 through 50-59 (only one participant was in 50-59 range). About 97 percent of participants' age was in 20-49 range. Table 11 and Figure 31 present the distribution of the participants' age. The average of hours per week of computer usage (work and recreation combined) of participants in the 2D condition is lower than participants' in the 3D condition, being 40.5 and 46.5 hours per week respectively (as shown in Figure 32).This difference was not significant. Participants' fields of work ranged from full-time students, military officers, engineering managers or project managers, and engineers. There was one participant who works as a contract engineer for military services (showed as "other field of work" in Table 12 and Figure 33 respectively). Fifty-one percent of participants were engineers, engineering managers, or project managers. Table 12 and Figure 33 present the participants' field of work. The average value of years of working experience of participants in 2D condition is lower than participants' in 3D conditions, being 9 and 12.6 years respectively. The years of working experience related to engineering of participants in 2D and 3D conditions were close in value, being 6.5 and 7.4 years respectively. The average of years of working experience at the management level of participants in 2D condition is lower than participants' in 3D condition, being 2.7 and 5.5 years respectively. Table 13 summarizes years of working experience, years of working experience related to engineering, and years of working experience at the manage level. Sixty-four percent of all participants have been exposed to engineering economy in projects before participating in this experiment, as shown in Figure 34. All of participants have been exposed to engineering economy in class before participating in this experiment. Twenty-eight percent of all participants have been exposed to engineering economy sensitivity analysis in projects before participating in this experiment, as shown in Figure 35. Sixty-seven percent of the participants had taken an engineering economy at the undergraduate level before, as shown in Figure 36. All of participants have taken an engineering economy at the graduate level.

Age group	No Significant Differences between Participants in 2D Condition and Participants in 3D Condition (p-value > .05)
Color deficiency [a]	
Computer usage both work and recreation (hours/week)	
Years of working experience	
Years of working experience related to engineering	
Years of working experience at the management level	
Exposed to engineering economy before	
Exposed to engineering economy sensitivity analysis before	
Taken engineering economy at the undergraduate level before	
Taken engineering economy at the graduate level before	
Having basic knowledge in engineering economy	
Understanding the concept of sensitivity analysis in engineering economy	
Understanding the concept of one-at-a-time sensitivity analysis	
Understanding the concept of two-at-a-time sensitivity analysis	
Understanding the concept of three-at-a-time sensitivity analysis	
Understanding the concept of interaction among parameters in decision models	
[a] All participants have ability to perceive color used in the present study.	

Table 14 Display Type Results for Participants' Background Information

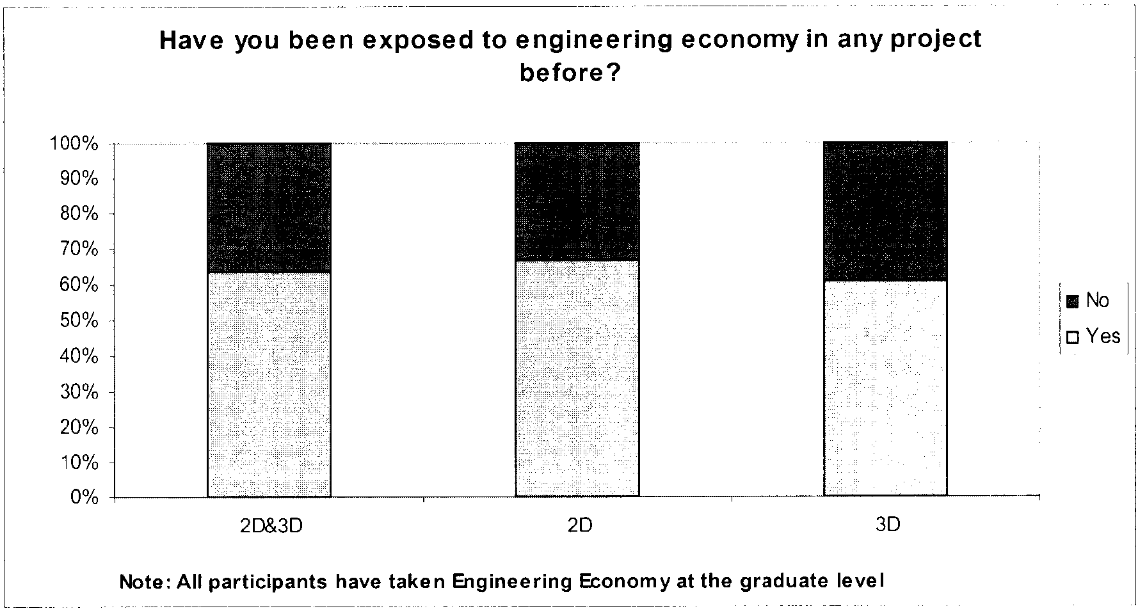


Figure 34 Participants' Background Information Question 8

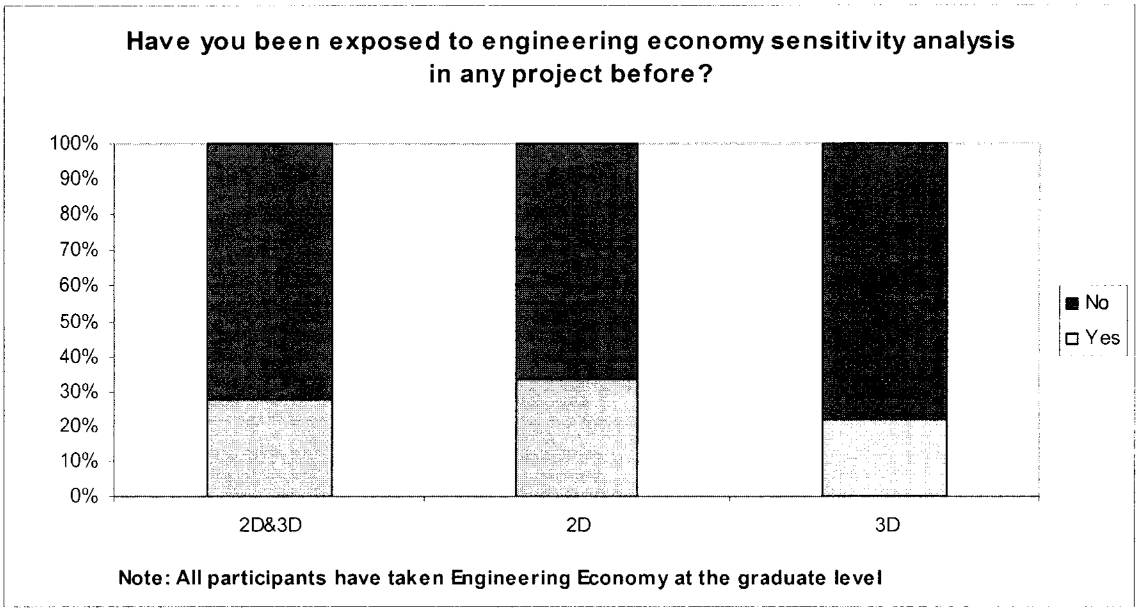


Figure 35 Participants' Background Information Question 9

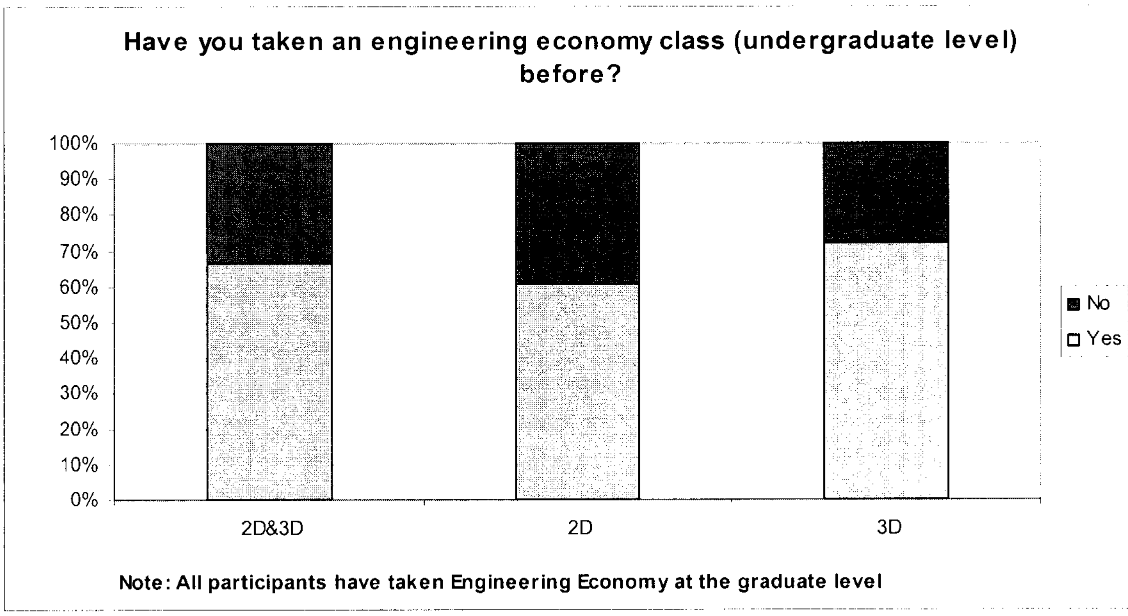


Figure 36 Participants' Background Information Question 10

The majority of the participants agreed that they have basic knowledge in engineering economy and that they understand the concept of sensitivity analysis in engineering economy (97 and 86 percent, respectively). Only one participant claimed that he disagreed that he has basic knowledge in engineering economy. More than 61 percent of participants agreed that they understand the concept of one-at-a-time, two-at-a-time, and three-at-a-time sensitivity analysis in engineering economy, being 83, 61, and 61 percent respectively. Seventy-eight percent of participants agreed that they understand the concept of interaction among parameters in decision models. Table 15 summarizes participants' knowledge related to engineering economy and sensitivity analysis (question 12.1-12.6). Figure 37 through Figure 42 show the results of questions 12.1-12.6 in participants' background information questionnaire by 100% stacked bar chart. Table 16 summarizes the results of accuracy and latency for the 2D and 3D conditions.

Questions	For All Participants		For Participants in the 2D Condition		For Participants in the 3D Condition	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Basic knowledge in engineering economy	4.56	0.65	4.56	0.78	4.56	0.51
Concept of sensitivity analysis in engineering economy	3.97	0.70	3.94	0.80	4.00	0.59
Concept of one-at-a-time sensitivity analysis	4.06	0.63	4.11	0.68	4.00	0.59
Concept of two-at-a-time sensitivity analysis	3.64	1.05	3.78	1.06	3.50	1.04
Concept of three-at-a-time sensitivity analysis	3.56	1.16	3.78	1.06	3.33	1.24
Concept of interaction among parameters	3.83	0.94	3.89	0.90	3.78	1.00

Table 15 Participants' Background Information Questions 12.1-12.6

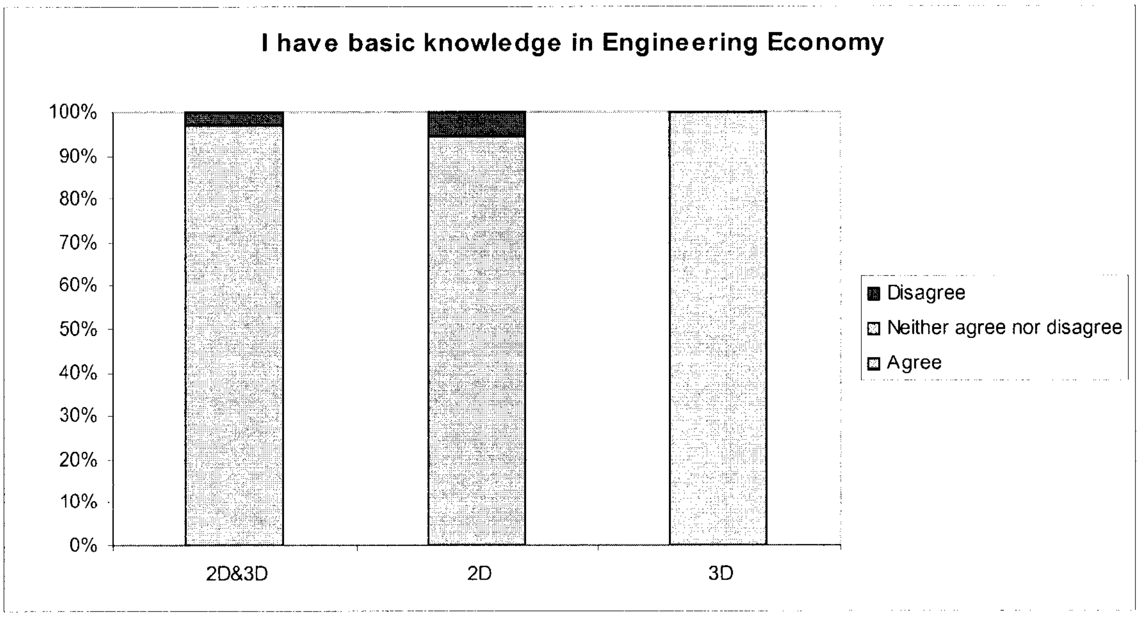


Figure 37 Participants' Background Information Question 12.1

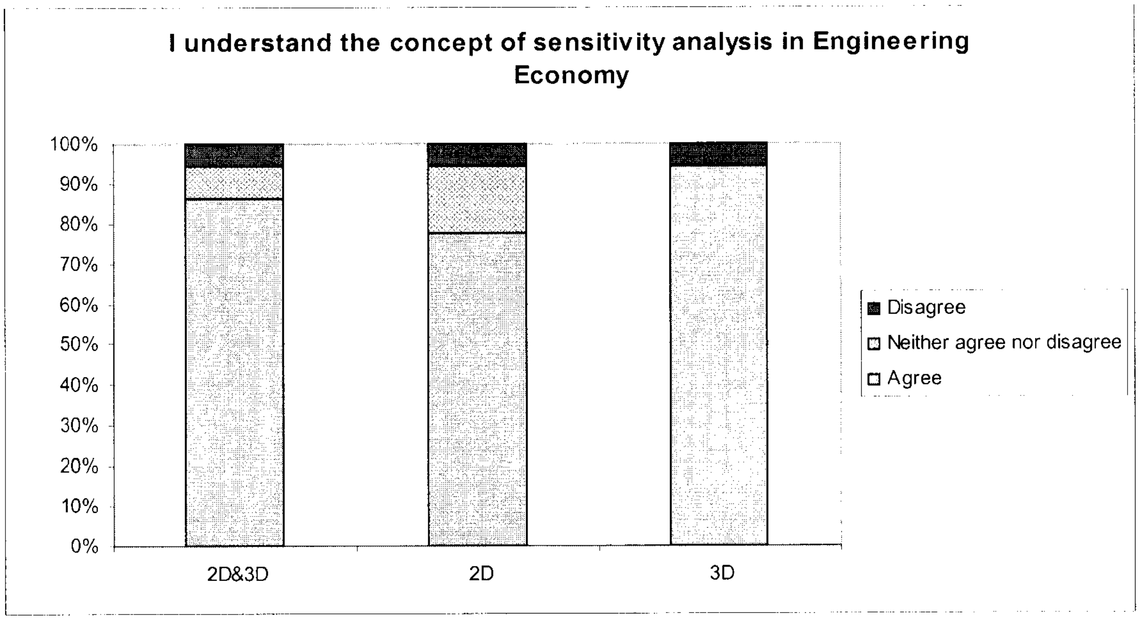


Figure 38 Participants' Background Information Question 12.2

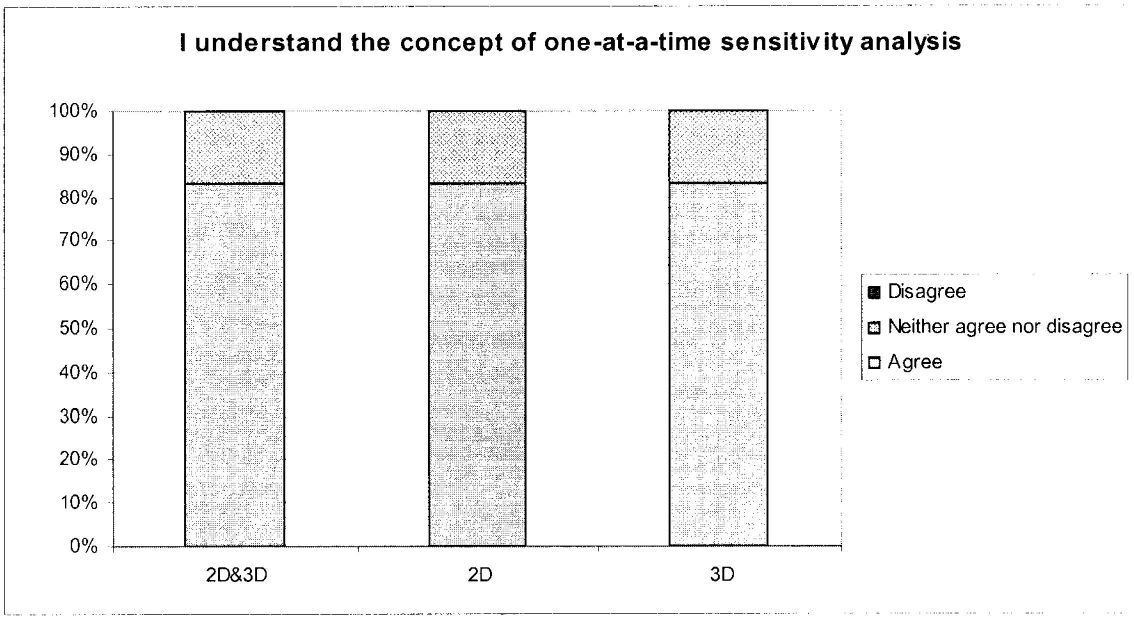


Figure 39 Participants' Background Information Question 12.3

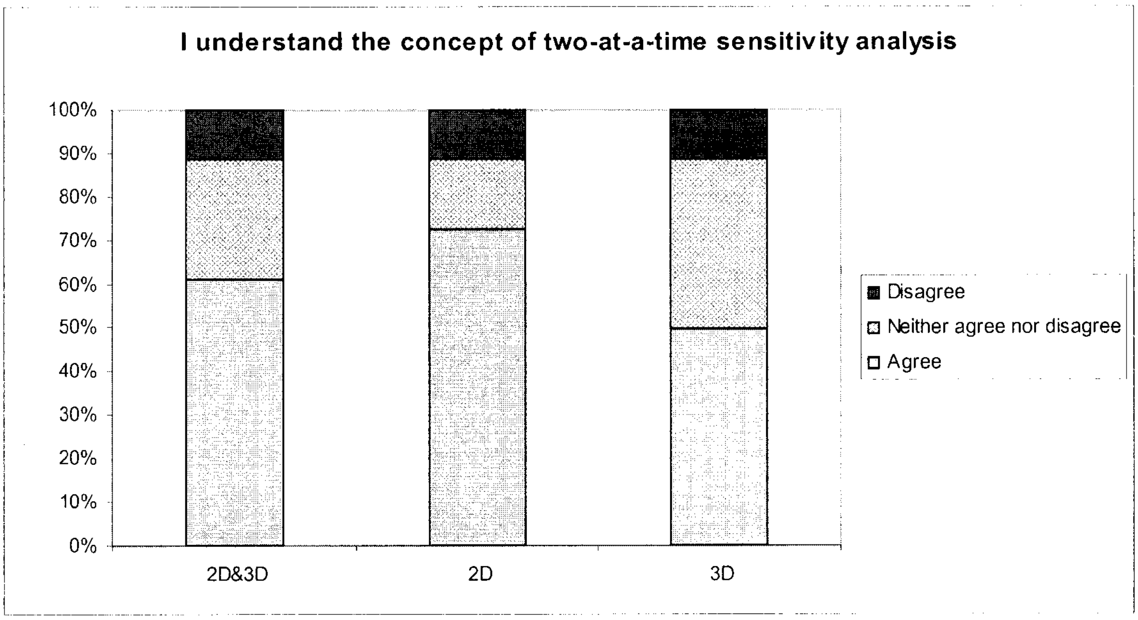


Figure 40 Participants' Background Information Question 12.4

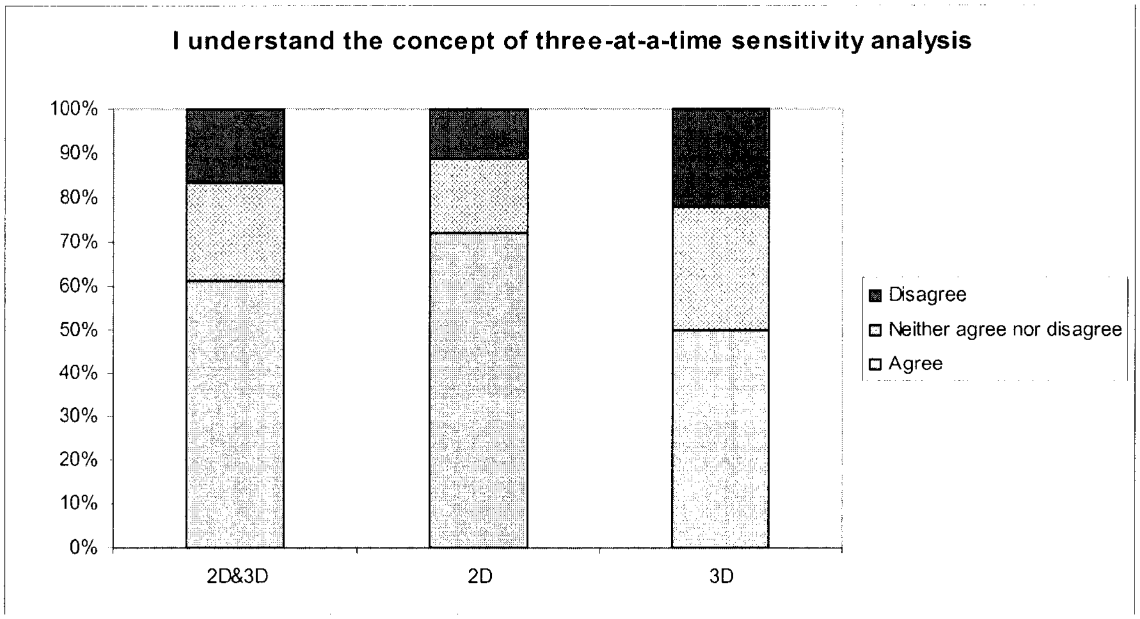


Figure 41 Participants' Background Information Question 12.5

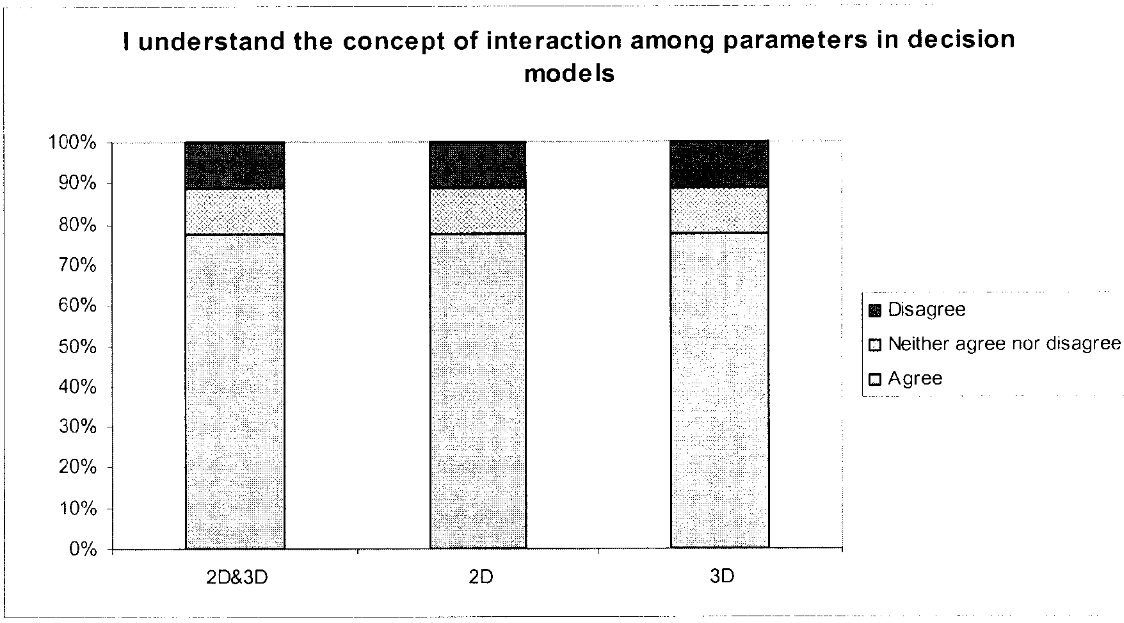


Figure 42 Participants' Background Information Question 12.6

Experimental Task	Significance	Power
Task 1: Accuracy	**Significant Difference**	.896
Task 1: Latency	No Significant Differences	.864
Task 2: Accuracy		.731
Task 2: Latency		.386

Table 16 Display Type Results for Accuracy and Latency

Accuracy

The results for accuracy scores were summarized in Table 17. There was a significant difference in the accuracy score of Task 1 with a power equal to .896. There were no statistically differences in the accuracy scores of Task 2 between the 2D condition and 3D condition with a power equal to .731 according to multiple independent t-tests with Bonferroni correction. Figure 43 and Figure 44 present accuracy scores of Task 1 and Task 2 in 100% stacked bar charts respectively.

Accuracy	For All Participants		For Participants in the 2D Condition		For Participants in the 3D Condition	
	n	%	n	%	n	%
Experimental task 1						
Correct	20	56%	6	33%	14	78%
Incorrect	16	44%	12	67%	4	22%
Total	36	100%	18	100%	18	100%
Experimental task 2						
Correct	14	39%	4	22%	10	56%
Incorrect	22	61%	14	78%	8	44%
Total	36	100%	18	100%	18	100%

Table 17 Display Type Results for Accuracy

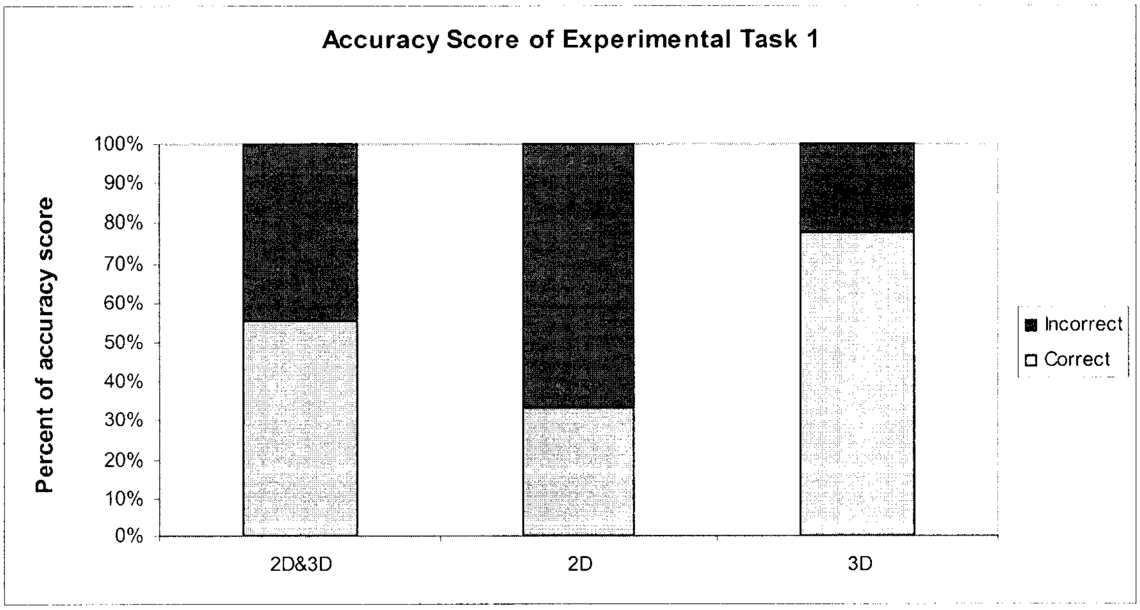


Figure 43 Accuracy Scores of Task 1 Display by 100% Stacked Bar Chart

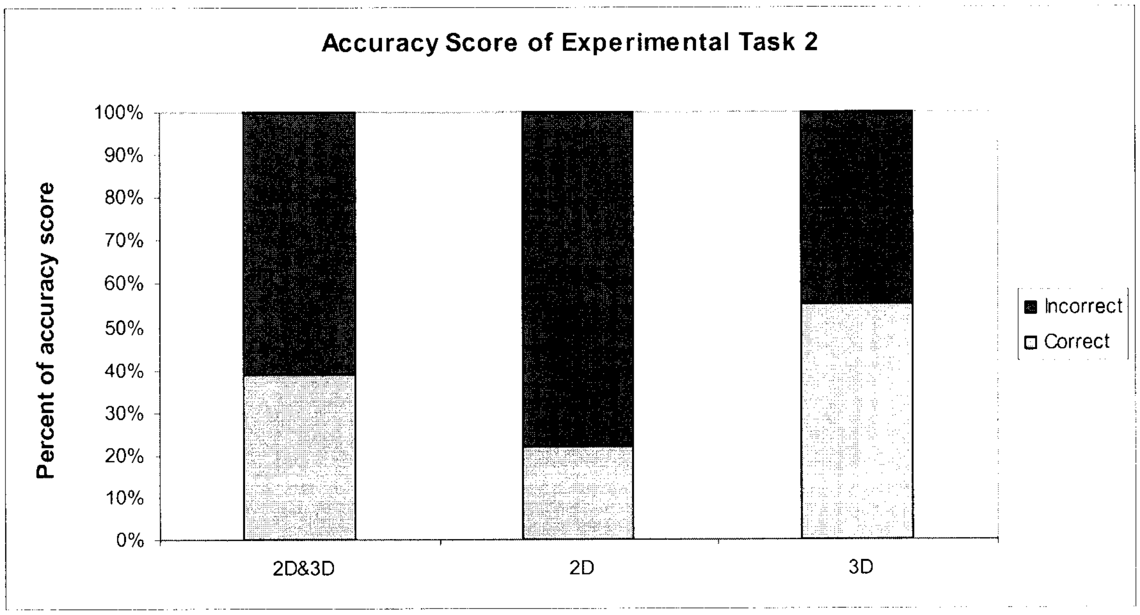


Figure 44 Accuracy Scores of Task 2 Display by 100% Stacked Bar Chart

Latency

The results for latency score were summarized in Table 18. There were no statistically differences in latency score of Task 1 and Task 2 between the 2D condition and 3D condition according to multiple independent t-tests with Bonferroni correction. Figure 45 and Figure 46 present latency scores of Task 1 and Task 2 in error bar plot respectively. Concerning the correlation between the latency and accuracy, there were no significant differences on both tasks at alpha level equal to .05.

Latency (sec)	N	Range	Min	Max	Mean	Std. Deviation
For All Participants						
Experimental Task 1	36	260	30	290	119.31	65.70
Experimental Task 2	36	353	39	392	161.64	81.30
For Participants in the 2D Condition						
Experimental Task 1	18	219	71	290	150.11	63.03
Experimental Task 2	18	349	43	392	184.28	89.59
For Participants in the 3D Condition						
Experimental Task 1	18	171	30	201	88.50	53.90
Experimental Task 2	18	272	39	311	139.00	67.05

Table 18 Latency of Task 1 and Task 2

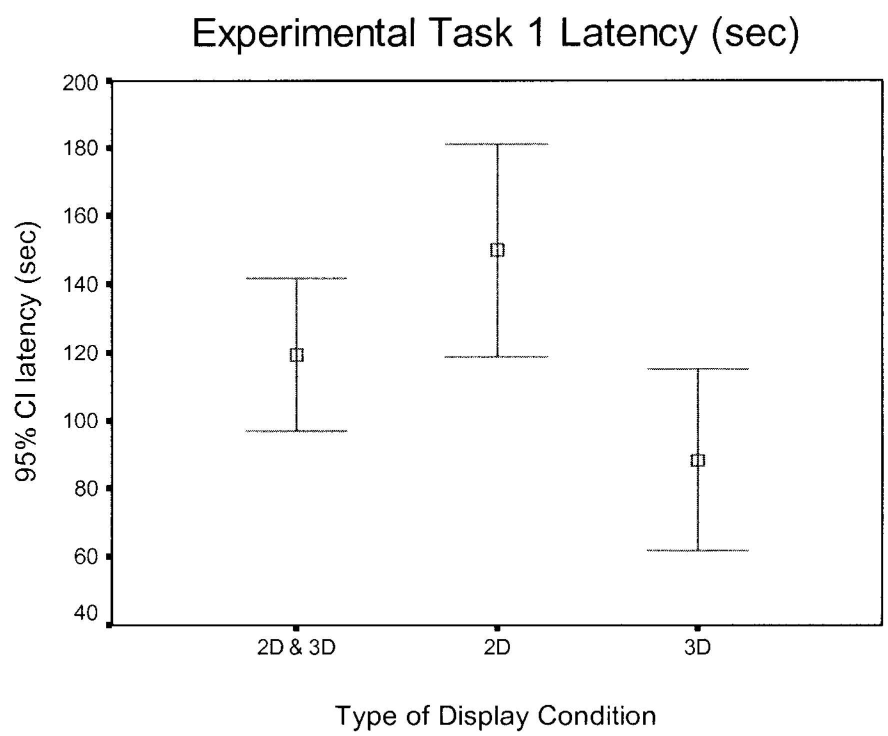


Figure 45 Latency of Task 1 Display by Error Bar Plot

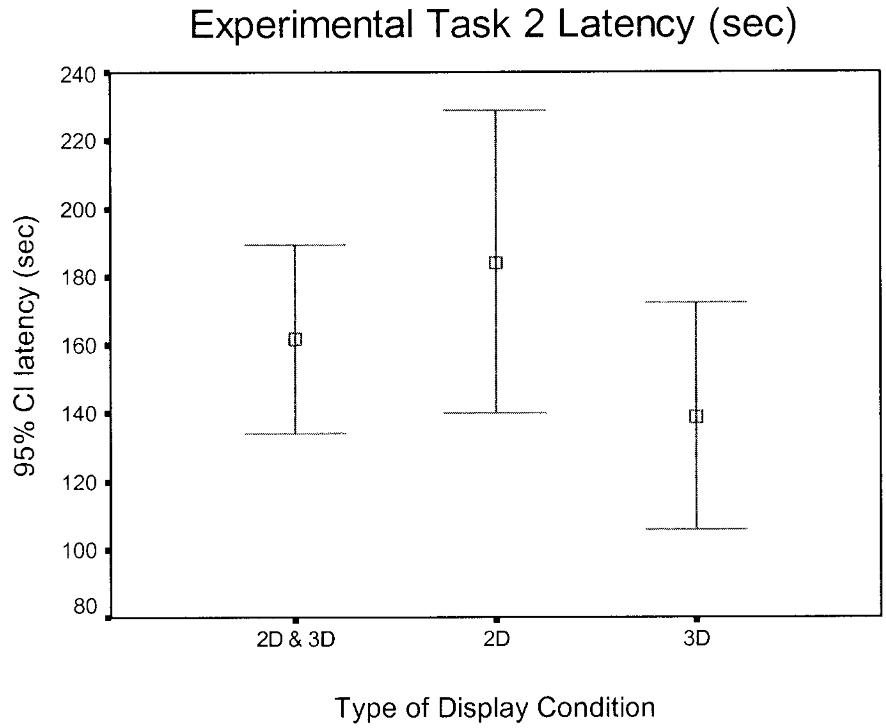


Figure 46 Latency of Task 2 Display by Error Bar Plot

After Session Opinion Questionnaire

The multiple independent t-tests with Bonferroni correction results for the after session opinion questionnaire based on users' satisfaction (from the five-point- Likert scale) are summarized in Table 19 and Table 20. According to multiple independent t-tests with Bonferroni correction, the ability to indicate reversal point or breakeven point in the 3D condition was statistically significant better than the 2D condition, t (34) = -4.51, p = 0.00015. Also, when the first question (understanding of the combined effects of three cash flow elements) was compared between the two display conditions, there was difference, being t(34) = -2.65, p = 0.01263. The 3D display shows a higher Likert score than the 2D display for a better understanding of sensitivity analysis information and extracting information but the difference was not significant (being t(34) = -3.49, p = 0.00167). Figure 47 through Figure 53 present participants' after session opinion questionnaire results in 100% stacked bar charts

Questions	For All Participants		For Participants in the 2D Condition		For Participants in the 3D Condition	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Understanding of the combined effects of three cash flow element	3.56	1.36	3.00	1.46	4.11	1.02
Helping me to get better understanding of sensitivity analysis	3.69	1.26	3.06	1.35	4.33	0.77
Easy to indicate reversal point or range (negative measure of merit)	3.78	1.29	3.00	1.33	4.56	0.62
From a managerial standpoint, the display helped me made better decision	3.75	1.20	3.39	1.33	4.11	0.96
Easy to extract information that I need	3.72	1.19	3.17	1.29	4.28	0.75
Display stressful to use	2.11	1.26	2.50	1.38	1.72	1.02
Display gave motivation to use	3.67	1.04	3.50	1.04	3.83	1.04

Table 19 Participants' After Session Opinion Questionnaire Results

Questions	Significant	Power
I found the display easy to understand the combined effects of three cash flow elements	No Significant Differences	0.711
I consider the display help me to get better understanding of sensitivity analysis		0.866
I found the display easy to indicate reversal point or range (negative measure of merit)	**3D Display Significantly Better than 2D Display**	0.996
From a managerial standpoint, the display helped me made a better decision	No Significant Differences	0.421
I found the display easy to extract information that I need		0.844
I found the display stressful to use		0.483
I found the display gave motivation to use		0.141

Table 20 Results of After Session Opinion Questionnaire

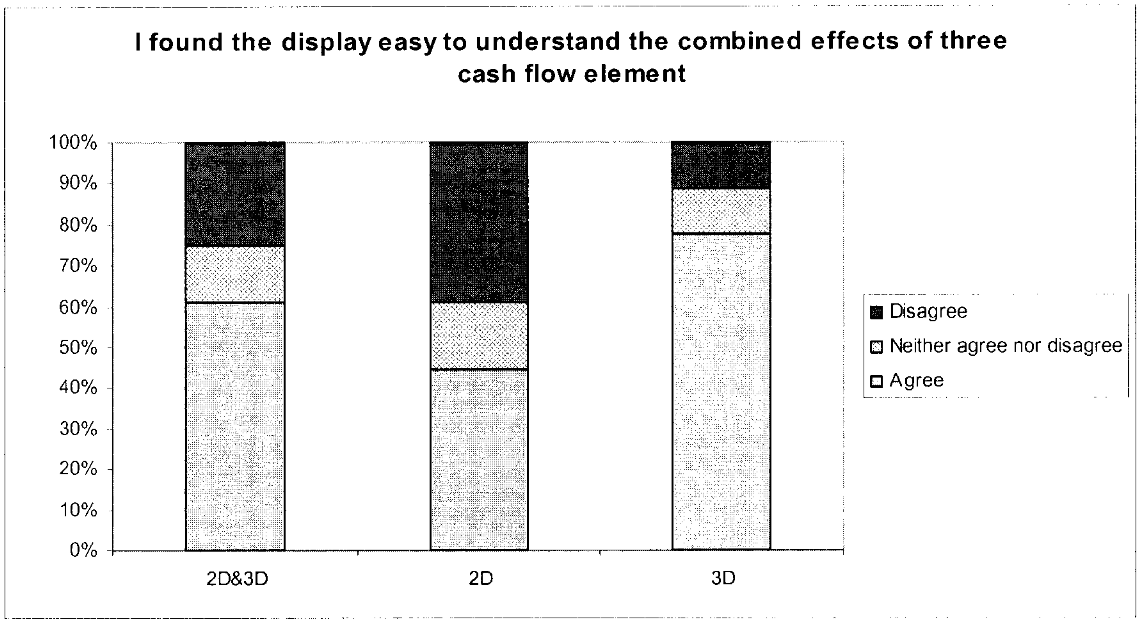


Figure 47 After Session Opinion Questionnaire Question 1

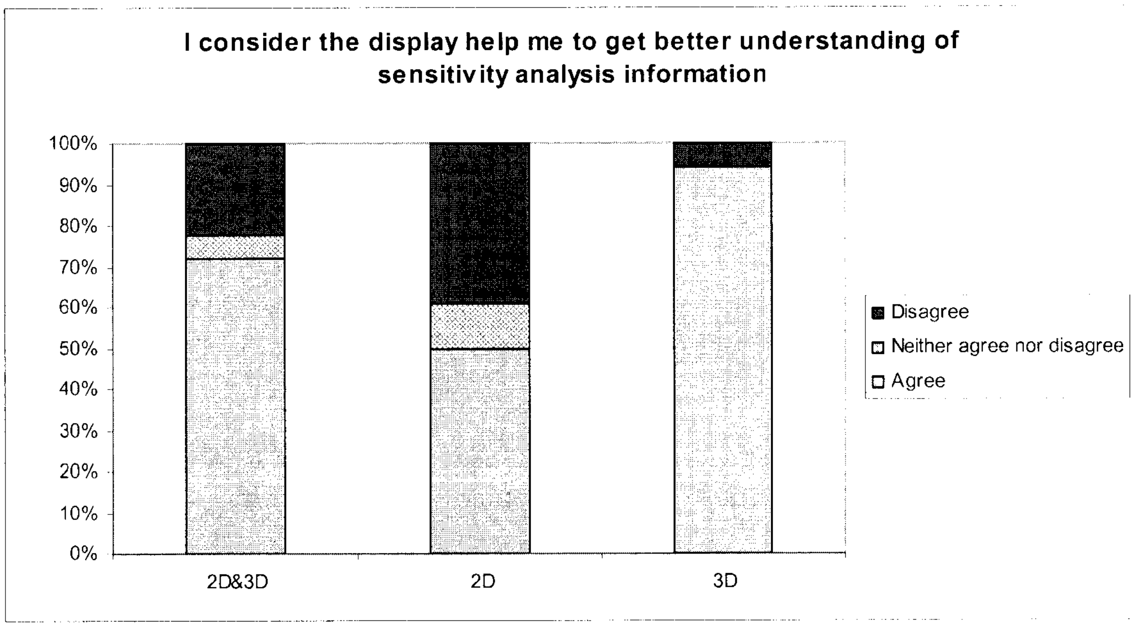


Figure 48 After Session Opinion Questionnaire Question 2

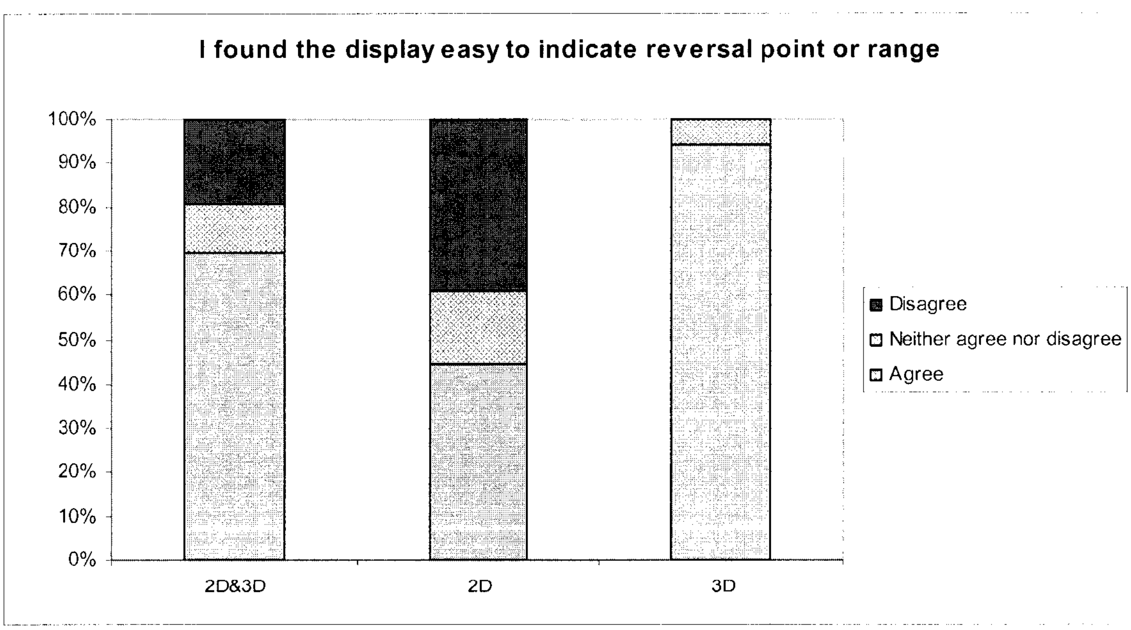


Figure 49 After Session Opinion Questionnaire Question 3

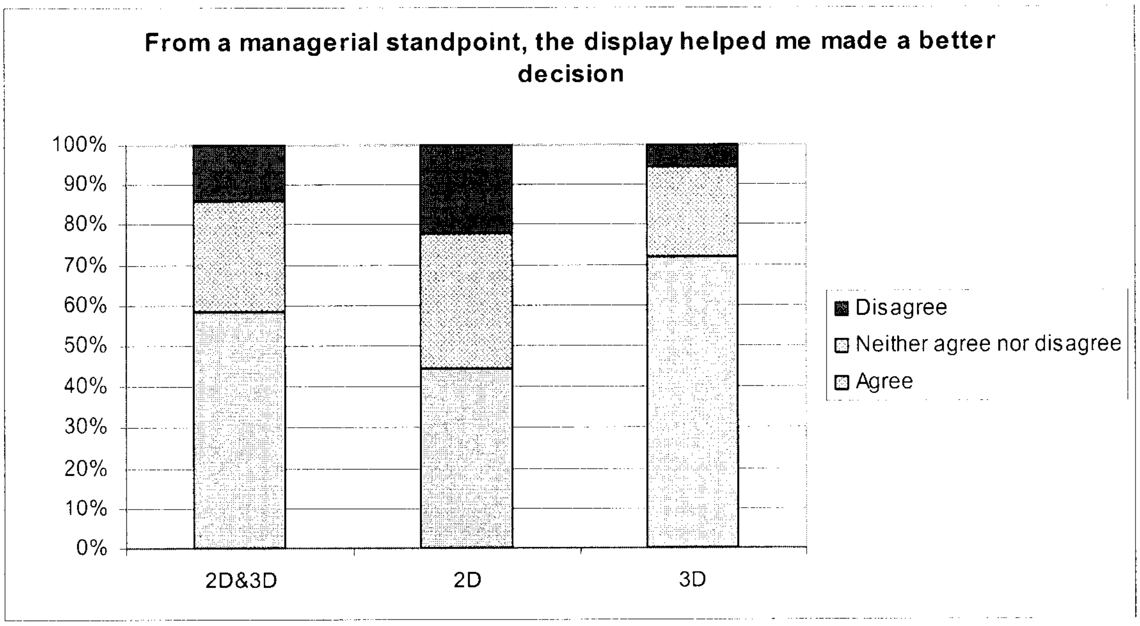


Figure 50 After Session Opinion Questionnaire Question 4

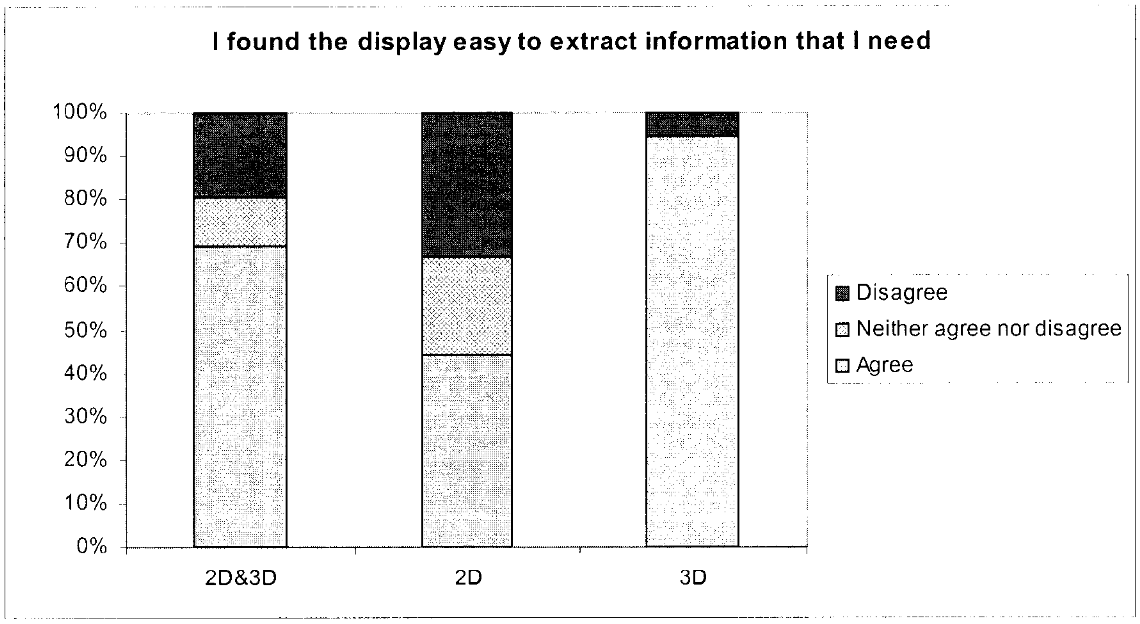


Figure 51 After Session Opinion Questionnaire Question 5

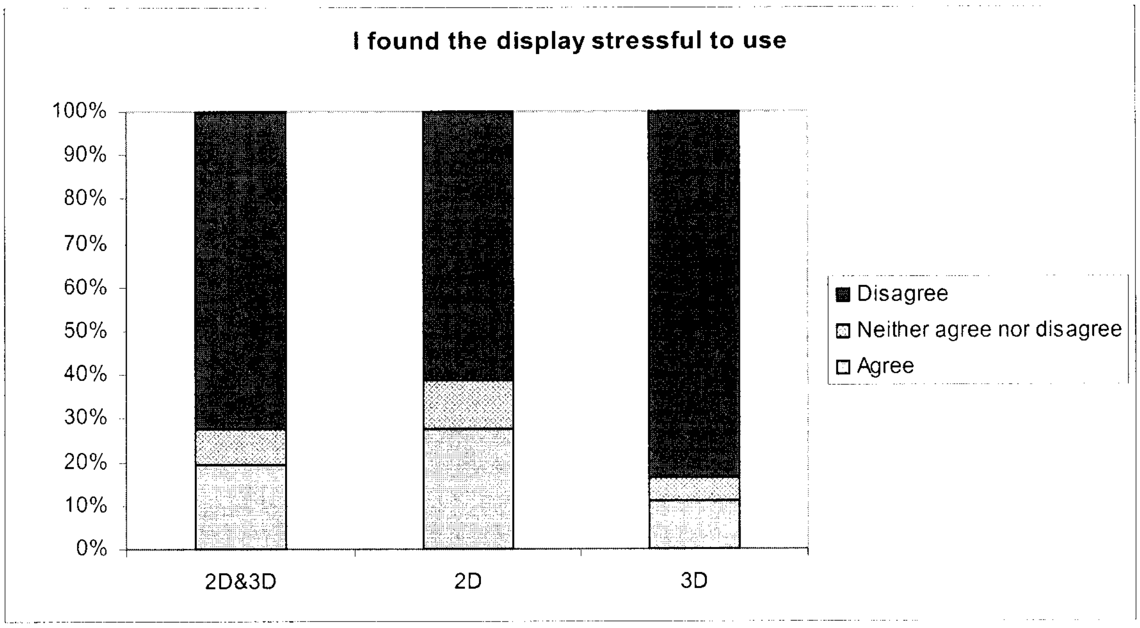


Figure 52 After Session Opinion Questionnaire Question 6

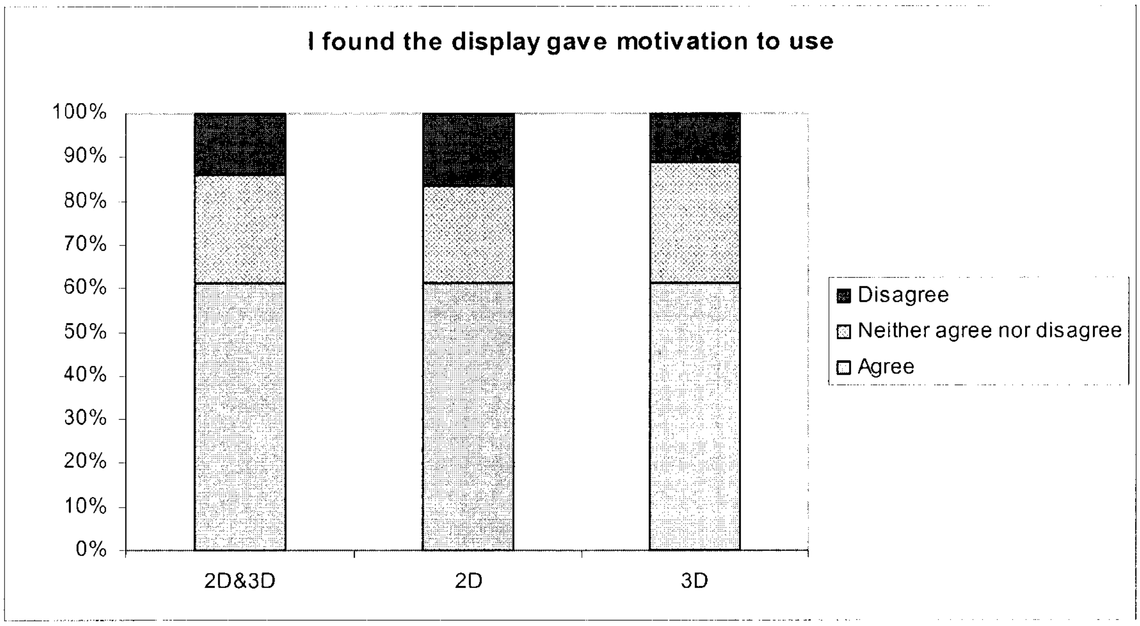


Figure 53 After Session Opinion Questionnaire Question 7

Correlation Analysis

Two of the assumptions underlying correlational statistics are that the relationship between the variables is linear and that there are no interactions present when multiple independent variables are studied (Whitley, 2002). The linear relationships can be displayed graphically by means of scatter plots (Cohen, Cohen, West, & Aiken, 2003). There was no significant correlation in the 2D and 3D conditions according to correlation analysis with Bonferroni correction.

Content Analysis

The results of content analysis of open-ended questions in after session questionnaires are organized as follows: (1) the strategies that the participants used for extraction information from the display, (2) the first information that the participants were looking for in the display, (3) other thoughts, feelings, or comments about this experiment, (4) why the 3D helps the participants making a good decision, (5) the advantages of the 3D display, (6) the disadvantages of the 3D display, and (7) other remarks.

Question: Did you have a strategy for extracting information from the display(s)?

If so, what was it?

Category	**n**	**%**
No strategy	6	32%
Look for patterns of change by each variable (one-at-a-time analysis)	4	21%
Looking at the general color trends and color degradations	4	21%
Looking at the height of the bars	2	11%
Dividing the good project section from the bad project section	1	5%
Focus one all three variables (three-at-a-time analysis)	1	5%
Two-at-a-time analysis	1	5%

Table 21 Content Analysis of Strategies for the 2D Condition

Category	**n**	**%**
Noticing the relationship between the variables	6	35%
Looking at the general color degradations to understand the relationship among variables	3	18%
Looking for breakeven (line, curve, and point)	2	12%
First look at the maximum and minimum value of PW	2	12%
The N values are not so clear	2	12%
No strategy	1	6%
Using the height of the bars to indicate trend	1	6%

Table 22 Content Analysis of Strategies for the 3D Condition

Question: What was the first information you looking for in the display

Category	n	%
Looking for each of the three variables separately and their effect on the PW (one-at-a-time analysis)	6	30%
Color for negative and positive PW	5	25%
Height of the bars	2	10%
Looking at two variables at a time	2	10%
Trend or pattern	2	10%
N/A	2	10%
Min/Max PW	1	5%

Table 23 Content Analysis of the First Information for the 2D Condition

Category	n	%
Negative areas (bars above the plane)	7	37%
Color variation	6	32%
Each variable at a time	4	21%
Cut-off point or breakeven area	1	5%
Min and Max PW then locate all variables	1	5%

Table 24 Content Analysis of the First Information for the 3D Condition

Question: Do you have any other thoughts, feelings, or comments about this experiment?

Category	n	%
N/A	6	35%
Recommend using different color	3	18%
2D is too difficult to understand for upper management	2	12%
It was a good experiment and well put together	2	12%
3D would be useful if you were used to reading it	1	6%
Impression of 3D graphic	1	6%
The color is helpful in deciphering the chart	1	6%
Participants feel like they are under pressure (i.e., while being asked questions to extract data, timing)	1	6%

Table 25 Content Analysis of Other Thoughts, Feelings, or Comments for the 2D Condition

Category	n	%
N/A	5	28%
Very useful display tool	5	28%
It's awkward to think in term of negative PW being in an upward direction (counter intuitive)	3	17%
It's a challenge to understand	2	11%
If you have the ability to look at the data from different sides or angles would help	1	6%
Could use it for what-if analysis	1	6%
Timing effect makes it a bit stressful	1	6%

Table 26 Content Analysis of Other Thoughts, Feelings, or Comments for the 3D Condition

Question: Did the 3D display help you make a good decision? (yes/no)? Why?

Category	n	%
Immediately answer (visualize) where projects go bad because negative and positive difference was more appellant and required less concentration	7	37%
N/A	3	16%
It's a clearer display	2	11%
Easy to identify magnitude	2	11%
Too fancy or too complicated	2	11%
It is easier to see how a change in one variable affects the other two variables	1	5%
Information is easy to extract or visualize	1	5%
Perspective makes it more difficult to read absolute values	1	5%

Table 27 Content Analysis of Why the 3D Helps the Participants Making a Good Decision from the Participants in the 2D Condition

Category	n	%
Easy to correlate interrelationship of the three variables	9	47%
It is easy to see where the PW goes negative due to the color change	4	21%
Could easily see the trends of the PW or transition from positive PW to negative PW/ It's easy to see a weighted visual display	3	16%
Unfamiliar with the graphic	2	11%
The perspective was not easy to use	1	5%

Table 28 Content Analysis of Why the 3D Helps the Participants Making a Good Decision from the Participants in the 3D Condition

Question: What pros and cons do you see for the use of 3D display in sensitivity analysis?

Category	n	%
Easier, clearer, and more visually to understand the result of varying multiple variables	8	57%
Easier to spot over where project goes bad (from gray to color to highlight difference)	2	14%
Less time to understand graphics	1	7%
The negative and positive difference was more appellant and required less concentration	1	7%
Fit all data neatly	1	7%
Easier to see magnitude	1	7%

Table 29 Content Analysis of the Advantages of the 3D Display from the Participants in the 2D Condition

Category	n	%
Easy to visualize the effects of three parameters at once	9	69%
3D display allows you to map more variable to more natural elements; X, Y, Z, and color	1	8%
It makes it very easy to spot clusters, anomalies, and translate	1	8%
It is easier to "see" the transition from positive PW to negative PW	1	8%
See the positive and negative clearer	1	8%

Table 30 Content Analysis of the Advantages of the 3D Display from the Participants in the 3D Condition

Category	n	%
Negative present worth is shown as a rise and not a fall	2	25%
Harder to read data (absolute values), perspective angle is confusing	2	25%
Too much information for one chart	1	13%
Time consuming to graph	1	13%
No additional information	1	13%
Smaller bars are hard to read	1	13%

Table 31 Content Analysis of the Disadvantages of the 3D Display from the Participants in the 2D Condition

Category	n	%
It might be different to use on people that have never used such a graph	4	50%
Not good for reading absolute values	2	25%
3D is too complicated	1	13%
User familiarization with counter intuitive negative PW in upward direction positive PW downward	1	13%

Table 32 Content Analysis of the Disadvantages of the 3D Display from the Participants in the 3D Condition

Question: Are there any other remarks you would like to make?

Category	n	%
N/A	8	44%
Showing bad project on top and color coded helping you to focus on what makes a bad	2	11%
Overall is pretty good experiment and set up really well	2	11%
I like the use of color because of it makes the graph easier to read	2	11%
The color is useful in both 3D and 2D graphic	1	6%
N and P on same site of chart seem to "cluttered"	1	6%
The 3D display provides a very useful tool to any project manager	1	6%
Recommend using different color	1	6%

Table 33 Content Analysis of Other Remarks from the Participants in the 2D Condition

Category	n	%
N/A	9	53%
A good way to see the effects on multiple changes	3	18%
The use of color for negative PW is good.	2	12%
Ns were hard for me to line up with the corresponding bars	1	6%
This is a lot easier to translate than multiple spiderplots	1	6%
There is not different between 2D and 3D	1	6%

Table 34 Content Analysis of Other Remarks from the Participants in the 3D Condition

CHAPTER VI

DISCUSSION, IMPLICATIONS, AND RECOMMENDATIONS

This chapter begins with a discussion of the results from the data analysis, followed by a discussion of the potential contributions to theory and research. Finally, it will include the limitations of the research and provide implications for future research.

Discussion

Concerning the participants' background information, the participants in this study tended to represent engineering managers or engineers who are at the management level. Forty four percent of the participants reported that they were engineering managers or had experiences at the management level in an engineering environment prior participating to this research. All of them were taking or had successfully taken an engineering economy course at the graduate level at the time of this study. Sixty-four percent of the participants reported that they had been exposed to engineering economy in real-life projects before the present study, just 28 percent of the participants had experiences in sensitivity analysis in engineering economy in real-world projects. Even lacking in real-world experiences, a large portion of the participants had or claimed to have a basic knowledge in engineering economy and sensitivity analysis. There was only one participant who reported that he disagreed that he had a basic knowledge of engineering economy. Further investigation revealed that he has 14 years in working experience related to engineering. He also took an engineering economy course at the undergraduate level (in addition to the graduate course), so he was included in the experiment.

Ninety-seven percent of the participants in the present study took an engineering economy class at the graduate level from the same instructor team. This was an advantage because of another confounding factor (differences in engineering school or instructor) was eliminated or reduced from the study. Concerning participants' computer usage, the average number of hour per week of the participants in the 2D and 3D conditions were close to regular normal working hour per week (40 hours per week). Concerning basic engineering economy knowledge and knowledge related to sensitivity analysis, the participants in the 2D and 3D conditions were statistically equivalent.

Concerning accuracy scores of experimental tasks, the result from the 3D condition was significantly better than the 2D condition in Task 1. A significance value of $\alpha = .05$ was used here due to the multiple tests performed and the increased probability of Type I error. The think aloud protocol and the content analysis revealed possible reasons why three-dimensional displays were superior to two-dimensional ones. The presentations of three variables (A, P, and N) variables in the 2D display seemed to confuse the participants in the 2D condition, especially the third variable (N). This is an indication of a complex mental integration of information. It is consistent with Dryer's (1996) research. He stated that increased information complexity is harder to represent in conventional 2D displays, which creates a need for display innovation. Problems with current 2D information representation techniques include limited dimensionality and limited amounts of information that can be portrayed in a display. According to Wickens, Todd, and Seidler (1989), limited dimensionality creates the need for multiple 2D representations that require the user to mentally integrate information across displays. Another reason might be that the 3D display corresponds to the participants' conceptual or mental model of the tasks. According to Rouse and Morris (1986), mental models are the mechanisms whereby humans are able to generate descriptions of systems purpose and form, explanations of system functioning and observed system states, and predictions of future system states. However, there was no significant difference between the 2D and 3D conditions in Task 2 at alpha level equal to .05. One possible explanation for this is that the negative PW is in an upward direction instead of downward direction. It is counter intuitive to a number of participants but on the other hand it emphasizes transition areas from positive PW to negative PW. Another possible reason could be familiarity of the display. A number of participants stated that they needed more time to become familiar with the 3D display. One participant said that 3D displays might be difficult for people who have never used such a representation.

Concerning latency of both experimental tasks, there were no significant differences between 2D and 3D conditions. One possible explanation for this might be the participants more focused on accuracy than quickness of response. Even though, managerial decision makings require decisions to be made within short period of time but accuracy of those decisions seem to be more important. Even though, the response time in the 2D and 3D conditions were statistically equivalent a number of people reported that 3D displays helped them to immediately visualize the overall trend, correlated interrelationship of the three variables, and indicate transition area or breakeven area. One person stated that he used "less time to understand the graphic."

Even though color was not a control variable in this study, post experiment discussions with participants of the present study and content analysis also suggest an advantage of using color as a coding variable. Nineteen percent of participants (21percent for 2D condition and 18 percent for 3D condition) used color scale as their main strategy to extract information from the display. Twenty eight percent of all participants (25 percent for 2D condition and 32 percent for 3D condition) looked at the color scale first when they first saw the displays. A number of people stated that the color stands out and they used the color scale to look for other information in the display such as trend, maximum and minimum of present worth values. One person stated that "the color is helpful in deciphering the chart." Another person said that color "highlights" and helped him to "spot" unacceptable projects (negative net present worth). The benefits of using color as a coding variable in the present study are generally consistent with previous researches (Levkowitz, 1997; Levkowitz & Herman, 1992; Robertson, 1988; Rogowitz & Treinish, 1996; Tufte, 1990; Ware, 1988; Williams et al., 2003). Concerning the after-session questionnaire, the participants reported that they could detect the reversal point or negative PW areas on the 3D condition better than the 2D one.

Implications and Recommendations

In general, the findings of the present study support consideration of the use of 3D display in presenting complex data for managerial decision making. The 3D advantage is almost certainly task specific. The research indicated that two-dimensional displays might provide better performance in low level tasks while 3D displays have better performance in some high level tasks. Thus, when choosing between 2D and 3D displays, the costs and benefits of each must be weighed against the type of task for which the display will be used. Generally, if the decision makers have to make a decision related to three variables, then using a 3D type of display will most likely result in better performance. The benefits of 3D displays also depend on their appearances to the decision makers. The displays should be consistent with the decision makers' mental model.

Results of this research raised several issues for future research as well as practical implication for information visualization. Various implementations of promising emergent features in the present study should be exercised and evaluated in other complex real-world information processing domains. Future research areas include three-dimensional information displays that have more integration (i.e., including more coding variables). Future research will use a larger sample size of participants, a re-designed 3D information display, and apply other visual encoding such as transparency. Based on the findings of this research, graphical display of the combined effects of four or more factors could be further investigated. This subsequent work, taken together, can then be viewed as a foundation of design principles and practices to affect better graphical design for engineering economy, managerial decision making, and other specific multivariable sensitivity related domains.

The findings of this research can be generalized to other graphical display research in sensitivity analysis and managerial decision making domains such as project management and decision science. In project management, there are three primary elements which are time, cost, and performance (Kerzner, 1998). With the findings of the present study, project managers can get better understanding of the relationships when these three major elements vary from their base cases. In many decision science domains, decision makers encounter with three or more variables with various values for these parameters. With the findings of this research, decision makers can also graphically investigate the combined effects of parameters with different increments of variation.

There are of course some limitations to the present study which constrain its generalizability. The first limitation concerns hours per week of computer usage (work and recreation combined); there are various kinds of computer tasks relating to computer usage. Some of participants may use the computer for "low level" tasks such as Internet browsing, word processing, e-mailing, etc. while the other participants may use computer for more complex graphical tasks such as 3D graphical design, finite element analysis, or computer-aided design (CAD). The second limitation of the present study was the fact that the displays were static in term of user interaction. The users did not have control of the 3D display and could not change the perspective of the display. If the users have the ability to control and manipulate the display, it may increase the accuracy score and the overall understanding of the information.

Conclusions

This research demonstrates a proof-of-concept for a three-dimensional information display to assist users (at the management level) in a decision making process in engineering economy. The experimental results showed that the three-dimensional displays provided better decision support than the two-dimensional ones in certain task specific situation. It is based on a theoretical framework derived from engineering economy, the cognitive sciences, and human computer interaction.

A three-dimensional information display was designed and an experiment was conducted which tested this three-dimensional integrated display against a traditional two-dimensional bar chart displaying identical data. With the tasks assigned (associated with three variables), the empirical results showed better performance of the three-dimensional integrated displays over two-dimensional ones at certain tasks. This result is consistent with previous research. According to Bennett, Toms, and Woods (1993), they stated that while integrated displays may generally be better for more complex tasks, they are only effective when their features are accurately mapped and correctly designed to the information of the task domain.

Specific design guidelines can be drawn from this research including reversal perspective, pseudocoloring, and integral display. Integration tasks such as decision making with three variables can be enhanced with appropriate use of visual representations. Prompted by this research effort, it is hoped that others will investigate ways to further develop 3D displays in engineering economy and related managerial decision making areas to make complex relationships more readily understood.

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APPENDIX A: OLD DOMINION UNIVERSITY HUMAN SUBJECT RESEARCH REVIEW APPLICATION FORM

OLD DOMINION UNIVERSITY
HUMAN SUBJECT RESEARCH REVIEW APPLICATION FORM

NOTES

NOTE 1: If you believe that your research satisfies an exemption, please append a separate memorandum identifying that exemption and describing in detail how the research satisfies the legal requirements of the exemption. Exempt studies that are non-federally supported should be submitted to one's respective college committee using the College Committee Application. Information regarding the College Committees may be obtained through one's Dean's Office or the Office of Research and Graduate Studies.

NOTE 2: Do not make conclusory statements such as "this research involves no risk." Such statements are not helpful and usurp the Board's role; instead, describe activities that involve a similar risk and justify the comparison. Explain why. For example, your opinion in question 13(c) of a research project requiring a chest x-ray might be that it involves an overall risk similar to that of a diagnostic chest x-ray during a comprehensive physical examination because ______ - a different project might involve an overall risk similar to that of commuting to class. In addition, ensure that you describe the procedures for preserving confidentiality in detail; you may have the responsibility to preserve subject confidentiality for many years to come.

NOTE 3: Membership of the Board changes; check with the Office of Research and Graduate Studies to ensure that the points of contact in your Informed Consent Document are up-to-date.

NOTE 4: Do not leave items blank in the Application, or fail to provide to the Board any poster, document, or other written communication to subjects. Such applications will be table/denied.

NOTE 5: Research may not begin until you have final approval. At the same time, research shall not continue beyond a stated continuing review date or one year from the date of final approval.

OLD DOMINION UNIVERSITY
HUMAN SUBJECT RESEARCH REVIEW APPLICATION FORM

Applicants		
Principal Investigator: Kawintorn Pothanun	Telephone: (757) 816-7774	E-mail: kpoth001@odu.edu
Department: Engineering Management and Systems Engineering	Fax Number: (757) 683-5640	Date: _9_/_29__/_2003_
Campus Address: Kaufman Engineering Hall 129		
Complete Title of Research Project: Sensitivity Analysis Graphical Display for The Combined Effects of Three Cash Flow Elements in Engineering Economy	Code Name of Project (One Word): Sensitivity	
Applicant Sponsor		
Faculty Sponsor (if student project): William Peterson, Ph.D.	Telephone: (757) 683-3758	E-mail: wpeterso@odu.edu
Department: Engineering Management and Systems Engineering	Fax Number: (757) 683-5640	
Campus Address: Kaufman Engineering Hall 129		
Experimenter (Person(s) actually coordinating and supervising an on-site data collection) If more experimenters exist than lines provide, please attach a separate list.		
Experimenter Name: Kawintorn Pothanun	Telephone: (757) 816-7774	Room #: Kaufman Engineering Hall 115
Experimenter Name:	Telephone:	Room #:
Experimenter Name:	Telephone:	Room #:

1. This study is being conduced as part of (check one):

☐ Faculty Research ☐ Graduate Student Research

☒ Doctoral Dissertation Project ☐ Honors or Individual Problems

☐ Masters Thesis ☐ Grant or Contract

☐ Other (specify):

2. Is this research project externally funded or contracted for by an agency or institution which is independent of the university?

Ξ No ☐ Yes

(If yes, indicate the granting or contracting agency and provide identifying information.)

Agency Name:
Mailing Address:
Point of Contact:
Telephone:(___)_____-_____

3. Has this project been reviewed by any other committee (university, governmental, private sector) for the protection of human research participants? If yes, indicate the committee and its decision in the comments section below.

Comments: No, it has not been reviewed by any other committee

4. General Arrangements

A. Where will the experiment be conduced? (If on-campus, include building name and room number.)
The data will be collected in Kaufman Engineering Hall 115

B. During what calendar period? October, 2003 - May, 2004

C. Date you wish to start research (MM/DD/YY): __10_/_20__/_2003_

5. How many participants will there be? 60

Indicate the number of: 30 Males 30 Females

Enumerate any additional defining characteristics, including age, of the subject population. (e.g., symptomatology, history, socio-economic status: All of the subjects will be ODU students (graduate) who are at least 18 years old. Participants must pass or are currently taking the ENMA 600 Cost Estimation and Financial Analysis class. Participants must have normal to corrected-to-normal vision.

6. Administration of Subjects

6a. How long will it take to run each research participant? 30 minutes

6b. Will research participants receive course credit for participating in the study?

Ξ Yes (If yes, please explain in comments section.)

☐ No

Comments: Participation in this research will result in extra credit (4 points to the final grade) determined by the ENMA 600 Cost Estimation and Financial Analysis instructor. ENMA 600 students will have three choices (1) do nothing (0 point), (2) extra assignment (4 points), and (3) participate in this research (4 points).

6c. Are there any penalties for participants who do not show up for a research session?

☐ Yes (If yes, please explain in comments section.)

Ξ No

Comments:

6d. Are there any other forms of participant compensation that may be used? (e.g. Money)

☐ Yes (If yes, please specify in comments section.)

Ξ No

Comments: Participants will have the opportunity to win a monetary prize of $10.00 based on their performance during the experiment.

7. Research Participant Population (check as applicable):

☐ Undergraduate Students

Ξ Advanced Students

☐ Non-student Subjects

Comments: Graduate students from Engineering Management and Systems Engineering Department

8. How will participants be recruited? (Please submit a copy of the sign-up sheet, newspaper advertisement, or any other protocol or procedure which will be used to recruit participants.)

Standard announcement on Experiments Board/Peer Advisor's Office (see Attachment 5) and in ENMA 600 Cost Estimation and Financial Analysis class.

9. Are research participants being used whose ability to give informed voluntary consent may be in question? (e.g., children, persons with AIDS, mentally disabled, psychiatric patients, prisoners.)

☐ Yes (If yes, explain in detail the procedures to be employed to enroll them and to ensure their protection.)

☒ No

10. Describe the rationale for the research project and the reason for utilizing the particular participant population in question.

The purpose of this research is to investigate graphical display of sensitivity analysis for the combined effects of three cash flow elements in engineering economy problems. The researcher plans to study how to improve graphical display of sensitivity analysis for the combined effects of three cash flow elements in engineering economy problem with three-dimensional graphical display and color scale. Since this is a engineering economy related experiment, the researcher expects the graduate student participants from Engineering Management and Systems Engineering department to be representative of the general engineering management level population.

11. Describe the experimental procedures that will be followed. (A brief but comprehensive statement of the methodology relating to the human subjects.)

Participants will be ODU graduate students from Engineering Management and Systems Engineering department. They will come to the lab (Kaufman Engineering Hall 115) and will be asked if they brought their glasses if they do not have normal vision. At the beginning of each session participants will be required to read and sign a Consent Form (see Attachment 1) and Background Information Form (see Attachment 2). The Consent Form will contain information about their role in the study along with their rights and responsibilities as a participant. Once they have completed the Consent Form and Background Information Form, the experimenter will instruct them about how to perform a series of engineering economy sensitivity analysis tasks (see Attachments 3). Next the participants will have the opportunity to practice the tasks. After the practice session, the participant will perform a task session. After the session participants will complete an

Opinion Questionnaire (see Attachment 4). The entire session should last approximately 30 minutes. When finished participants will be debriefed.

Attach copies of the following items:

- Ξ Research Protocol(s)
- Ξ Questionnaire
- ☐ Copies of any instructions or debriefings given
- ☐ If the research is part of a research proposal submitted for federal, state or external funding, submit a copy of the FULL proposal

12a. Describe in detail and assess (compare to non-research related activity) ANY potential harm of the research regardless of likelihood. (e.g., physical, psychological, release of confidential information, or other.)

The only risks that would be associated with this experiment are those associated with regular computer usage.

12b. Describe WITH supporting information (justify) the likelihood (compare to non-research related activity) of EACH harm.

As college graduate students the subjects are regularly required to take exams. Therefore, they must endure this degree of mental fatigue on a regular basis. If these subjects were significantly harmed by this degree of mental fatigue they would not be in college.

12c. For each potential harm, the committee will also need for its review:

☐ A detailed account of the experimental procedure to be employed creating the harm.

☐ A detailed account of any mitigating procedures.

☐ The script that will be followed by the experimenter when the participant is appraised of potential harm and likelihood (risk) prior to the subject's choice 3to participate.

☐ A detailed, comparative statement of the risk (harm or likelihood) in the consent form.

☐ The plans and procedures that will be implemented for the protection of the subject should a serious risk materialize (adverse event.)

After this, you may separately describe your opinion of the overall seriousness of such risks associated with the experimental procedures. If chosen alternatives of research create potential risks, describe other methods, if any that were considered and why they will NOT be used.

13. Describe the procedures that will be used to obtain Informed Consent and attach the Informed Consent Document (follow the guidelines for preparation of the University Informed Consent Form. Note: Participants MUST be given a description of the procedures and rationale for the study to the extent possible. The benefits and ANY risks associated with participating in the study MUST be enumerated. The participants MUST be informed of their right to terminate the experiment at any time. If there is no risk associated with the study and participants' signature on the informed consent sheet is the only identifying information about the name of the participant, then the participants' signature may not be necessary.

The participants will be asked to read and sign an Informed Consent form (see Attachment 1). No names or other identifying information will be asked or used in this research.

14. Will the deliberate deception of research participants be involved as part of the experimental procedure?

☐ Yes
Ξ No

If yes, explain the nature of the deception, why it is necessary, any possible risks that may result from the deception, and the nature of the debriefing with specific reference to the deception.

15. Does the study require special evaluation and screening of potential participants to determine their appropriateness for inclusion in the study?

☐ Yes
Ξ No

If yes, briefly elaborate the screening process and attach the screening questionnaire.

16. Are subjects equitably chosen for participation in the study (i.e., do research participants come from a variety of locations, races, or circumstances and, hence, have an equal change of being selected?)

Ξ Yes

☐ No

If no, specify and justify in detail below:

17. Will any aversive or painful procedures be employed (e.g., shock, the threat of shock or punishment, experimentally induced stress?)

☐ Yes

Ξ No

If yes, specify and justify in detail below:

18. Describe in detail the procedures for protecting the anonymity (meaning that no one will ever be able to know the names) of the research participants. If anonymity is impossible, then describe in detail those procedures for safeguarding data and confidential records. These procedures relate to how well you reduce the risk that a subject may be exposed or associated with the data.

Nominal codes rather than names will be associated with each participant's data.

19. Assess the potential benefits that may accrue to both the individual participant as well as to others as a result of the proposed study. Do the potential benefits justify the possible risks involved? Although you may mention general benefits to society, such speculative benefits should not be presented to a subject as a direct benefit for informed consent.

Participating in experiments allows graduate students to see firsthand how research in engineering management and systems engineering is conducted. They will specifically learn how three-dimensional graphical display and color scale assist in sensitivity analysis of the combined effects of three cash flow elements in engineering economy problems. They will receive extra credit determined by the ENMA 600 Cost Estimation and Financial Analysis instructor. The experimenter will be responsible for reporting the credits to the engineering management class instructor.

20. Briefly explain the nature of the training and supervision of anyone who is involved in the actual data collection, research design, or in conducting the research. Attach a copy of the NIH Mandatory Training letter, if applicable.

Kawintorn Pothanun (principal investigator) has completed the NIH's Human Protection Education for Research Teams online course (see attachment 6).

PLEASE NOTE:

- You may begin research when the University Human Subjects Review Board gives you final WRITTEN notice of its approval.
- You MUST inform the committee of ANY adverse event, changes in the method, personnel, funding, or procedure.
- At any time the committee reserves the right to re-review a research project, to request additional information, to monitor the research for compliance, to inspect the data and consent forms, to interview subjects that have participated in the research, and if necessary to terminate a research investigation.

Principal Investigator (Must be original signature) **Date**

Faculty Sponsor (Must be original signature) **Date**

Note: If the principal investigator is a STUDENT, then this form MUST be countersigned by a faculty sponsor who will assume responsibility for ensuring compliance with appropriate legal guidelines.

APPENDIX B: INFORMED CONSENT FORM

Old Dominion University Informed Consent Form

INFORMED CONSENT DOCUMENT

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES.

TITLE OF RESEARCH: Sensitivity Analysis Graphical Display for The Combined Effects of Three Cash Flow Elements in Engineering Economy

RESEARCHERS:
Kawintorn Pothanun, ABD, Engineering management and Systems Engineering Department

DESCRIPTION OF RESEARCH STUDY:
Sensitivity analysis is one of the most important steps in engineering economy decision-making. In past research, sensitivity analysis has been divided into three categories (1) one-at-a-time analysis, (2) the combined effects of two cash flow elements (i.e., interested rate (i) and useful life (N)), (3) the combined effects of three or more cash flow elements (i.e., initial investment (P), interested rate (i) and useful life (N)). Graphical displays for one-at-a-time analysis and the combined effects of two cash flow elements analysis are generated via two-dimensional graphical display techniques such as spider plot diagram, area chart, and bar chart. The current research examines three-dimension graphical display for sensitivity analysis for the combined effects of three cash flow elements performance.

During the experiment, you will be asked to view and decode 2D or 3D graphical displays presented on a color computer monitor. You will be given a short tutorial to familiarize you with the task environment before actual task performance commences. The entire experiment should last approximately 30 minutes.

EXCLUSIONARY CRITERIA:
To participate, you must have normal vision or corrected-to-normal vision. Therefore, if you normally wear eyeglasses, or contact lenses you will need to wear them to participate. You must be at least 18 years old.

RISKS AND BENEFITS:
RISKS: The risks from this study are similar to those associated with normal computer usage. However, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: You will receive extra credit determined by the ENMA 600 Cost Estimation and Financial Analysis instructor. You may receive similar credit by participating instead in an alternative assignment from the instructor.

COSTS AND PAYMENTS:
We are unable to give you payment for participating in this study. However, you will earn a $10.00 prize if you have the best experimental task performance.

CONFIDENTIALITY:
Your participation in this research will be held confidential by the experimenter. Following determination of the person who earns the $10 prize for best performance, the researcher will remove identifiers from the information. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you. Of course, your records may be subpoenaed by court order or inspected by government bodies with oversight authority.

WITHDRAWAL PRIVILEGE:
It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will not affect your relationship with Old Dominion University, or otherwise cause a loss of benefits to which you might otherwise be entitled. The researchers reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation.

COMPENSATION FOR ILLNESS AND INJURY:
If you agree to participate, then your consent in this document does not waive any of your legal rights. However, in the event of harm, injury, or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact Dr. Bill Peterson at 757-683-3758 or Dr. David Swain from the Old Dominion University Office of Research and Graduate Studies, 757-683-6028.

VOLUNTARY CONSENT:
By agreeing to participate, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researcher should have answered any questions you may have had about the research. If you have any questions later on, then the researcher should be able to answer them:

Kawintorn Pothanun, 757-816-7774 or kpoth001@odu.edu

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. David Swain, at 757-683-6028, or the Old Dominion University Office of Research and Graduate Studies, at 757-683-3460.

By signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

------------------------------------	------------------------------------	------------------
Participant's Name	Participant's Signature	Date

INVESTIGATOR'S STATEMENT:
I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

------------------------------------	------------------------------------	------------------
Investigator's Name	Investigator's Signature	Date

APPROVED
HUMAN SUBJECTS REVIEW COMMITTEE

OCT 17 2003

YEAR FROM ABOVE DATE.
STION - 757-683-3460

Human Participant Protections Education for Research 1

Completion Certificate

This is to certify that

Kawintorn Pothanun

has completed the **Human Participants Protection Education for Research Teams** online course, sponsored by the National Institutes of Health (NIH), on 08/16/2003.

This course included the following:

- key historical events and current issues that impact guidelines and legislation on human participant protection in research.
- ethical principles and guidelines that should assist in resolving the ethical issues inherent in the conduct of research with human participants.
- the use of key ethical principles and federal regulations to protect human participants at various stages in the research process.
- a description of guidelines for the protection of special populations in research.
- a definition of informed consent and components necessary for a valid consent.
- a description of the role of the IRB in the research process.
- the roles, responsibilities, and interactions of federal agencies, institutions, and researchers in conducting research with human participants.

APPENDIX C: PARTICIPANT BACKGROUND INFORMATION FORM

PARTICIPANT BACKGROUND INFORMATION FORM

No.: ____________ Date: _________ Time: __________

The purpose of this questionnaire is to collect background information for participants in this experiment. This information will be used strictly for this experiment and for research purposes only. Please complete each item to the best of your ability.

1. Please specify your age group

☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ 60-69 ☐ 70-79

2. Have you ever been diagnosed as color blind or deficient?
   - ☐ Yes
   - ☐ No

3. How many hours per week do you use computers (work and recreation combined)?

____

4. Please describe your field of work? (you can select more than one)
   - ☐ Full-time student
   - ☐ Military officer
   - ☐ Engineering manager or Project engineer
   - ☐ Engineer
   - ☐ Financial related
   - ☐ Educational related
   - ☐ Other________________________

5. How many years of working experience do you have?________

6. How many years of working experience related to engineering do you have?___________

7. How many years of working experience at the management level do you have?_________

8. Have you been exposed to engineering economy in any project before?
   - ☐ Yes
   - ☐ No

9. Have you been exposed to engineering economy sensitivity analysis in any project before?
   - ☐ Yes
   - ☐ No

10. Have you taken an engineering economy class (undergraduate level) before?
    - ☐ Yes, when (year)__________
    - ☐ No

11. Have you taken an engineering economy class (graduate level) before?
    - ☐ Yes, when (year)__________
    - ☐ Currently taking in this semester

12.	**1. Strongly disagree**	**2. Partly disagree**	**3. Neither agree nor disagree**	**4. Partly agree**	**5. Strongly agree**
12.1 I have basic knowledge in engineering economy					
12.2 I understand the concept of sensitivity analysis in engineering economy					
12.3 I understand the concept of one-at-a-time sensitivity analysis (i.e., change one parameter and observe the output of the decision model)					
12.4 I understand the concept of two-at-a-time sensitivity analysis (i.e., change two parameters simultaneously and observe the output of the decision model)					
12.5 I understand the concept of three-at-a-time sensitivity analysis (i.e., change three parameters simultaneously and observe the output of the decision model)					
12.6 I understand the concept of interaction among parameters in decision models					

APPENDIX D: PARTICIPANT INSTRUCTION

PARTICIPANT INSTRUCTIONS

Pre-test

Color sensitivity:

Participants will be positioned about 75cm from display monitor and read the description of the image. Collect information if participants unable to follow the description of the image.

[Now, show Ishihara Color Test on the monitor. The test will be simplified to 6 tests; test 1, one of tests 2 or 3, one of tests 4, 5, 6 or 7, one of tests 8 or 9, one of tests 10, 11, 12 or 13 and one of tests 14 or 15.]

Sensitivity Analysis Graphical Display Experiment

[Before starting, make sure that the display is set up and ready to go.]

An engineering project can have many cash flow elements involve such as interest rate, unit cost, initial investment, project useful life, annual benefit, etc. Each of project's cash flow elements will affect the overall project's measure of merit (present worth, annual worth, future worth, etc.).

Interaction among selected cash flow elements is considered an important element that a project manager or engineer should be concern. With using the following displays, one can perform sensitivity analysis of the combined effects of three cash flow elements.

[Show Spiderplot]

Display Familiarization Session

We will now do a display familiarization session. You will see either (1) sensitivity bar chart display or (2) three-dimensional display. You will verbally be explained the content of the display.

[Make sure participant is looking at the Practice Display]

[Show sensitivity bar chart or three-dimensional display]

Experiment Session

You will see either (1) sensitivity bar chart display or (2) three-dimensional display. You will be verbally asked questions about the display. You are to respond with the correct answer. The accuracy and quickness of your responses will be recorded. Accuracy and quickness will determine your performance with the priority on getting an accurate response.

[Now we will do the experiment session]

APPENDIX E: AFTER SESSION OPINION QUESTIONAIRE FOR THE 2D CONDITION

No.: ______________ **Date:** __________ **Time:** ____________

Thank you for participating in this research project. Please complete the following items by entering the number of your choice on the answer sheet. Your answers are completely confidential.

Please rate the sensitivity analysis graphical display on the following dimensions:

	Sensitivity bar chart display				
	1. Strongly disagree	**2. Partly disagree**	**3. Neither agree nor disagree**	**4. Partly agree**	**5. Strongly agree**
1. I found the display easy to understand the combined effects of three cash flow elements					
2. I consider the display help me to get better understanding of sensitivity analysis information					
3. I found the display easy to indicate reversal point or range					
4. From a managerial standpoint, the display helped me made better decision					
5. I found the display easy to extract information that I need					
6. I found the display stressful to use					
7. I found the display gave motivation to use					

8. Did you have a strategy for extracting information from the display(s)?
If so, what was it?

Sensitivity bar chart display	____________________ ____________________ ____________________

9. What was the first information you looking for in the display for sensitivity analysis of the combined effects of three cash flow elements?____________________
What was the strategy?

Sensitivity bar chart display	____________________ ____________________ ____________________

10. Do you have any other thoughts, feelings, or comments about this experiment?

____

____

____

____

____

____

APPENDIX F: AFTER SESSION OPINION QUESTIONAIRE FOR THE 3D CONDITION

AFTER SESSIONS OPINION QUESTIONNAIRE

No.: _______________ **Date:** _________ **Time:** _____________

Thank you for participating in this research project. Please complete the following items by entering the number of your choice on the answer sheet. Your answers are completely confidential.

Please rate the sensitivity analysis graphical display on the following dimensions:

	Three-dimensional display				
	1. Strongly disagree	2. Partly disagree	3. Neither agree nor disagree	4. Partly agree	5. Strongly agree
1. I found the display easy to understand the combined effects of three cash flow element					
2. I consider the display help me to get better understanding of sensitivity analysis information					
3. I found the display easy to indicate reversal point or range					
4. From a managerial standpoint, the display helped me made better decision					
5. I found the display easy to extract information that I need					
6. I found the display stressful to use					
7. I found the display gave motivation to use					

8. Did you have a strategy for extracting information from the display(s)?
If so, what was it?

Three-dimensional display	______________________________ ______________________________ ______________________________

9. What was the first information you looking for in the display for sensitivity analysis of the combined effects of three cash flow elements?____________________________
What was the strategy?

Three-dimensional display	______________________________ ______________________________ ______________________________

10. Do you have any other thoughts, feelings, or comments about this experiment?

____
____
____
____
____
____

APPENDIX G: AFTER SESSION OPINION QUESTIONAIRE FOR COMPARISION BETWEEN THE 2D AND THE 3D CONDITIONS

1. Did the 3D display help you make a good decision? (yes/no)____________
Why?____
____
____
____
____

2. What pros and cons do you see for the use of 3D display in sensitivity analysis?
____
____
____
____
____

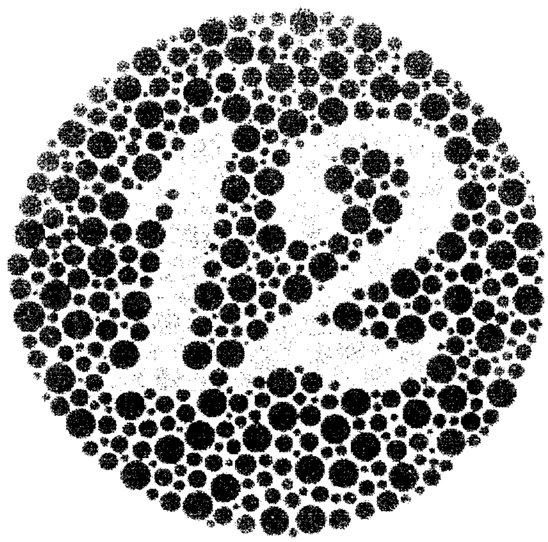
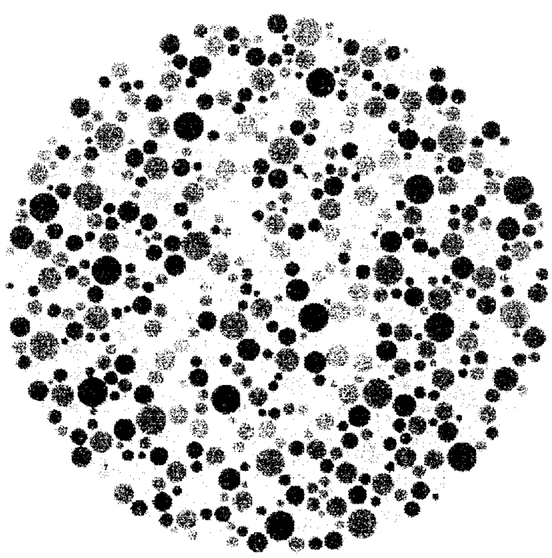
3. Are there any other remarks you would like to make?
____
____
____
____
____

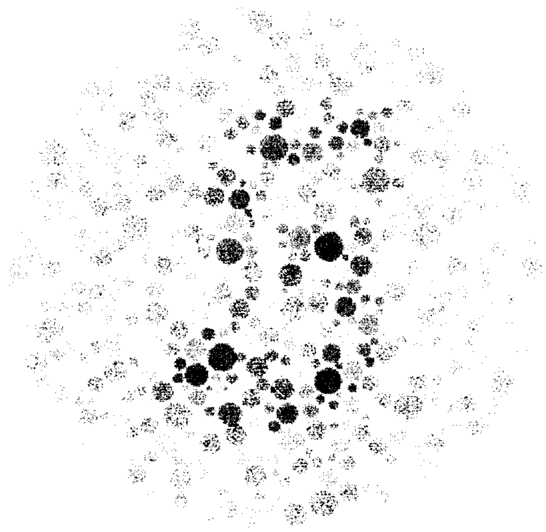
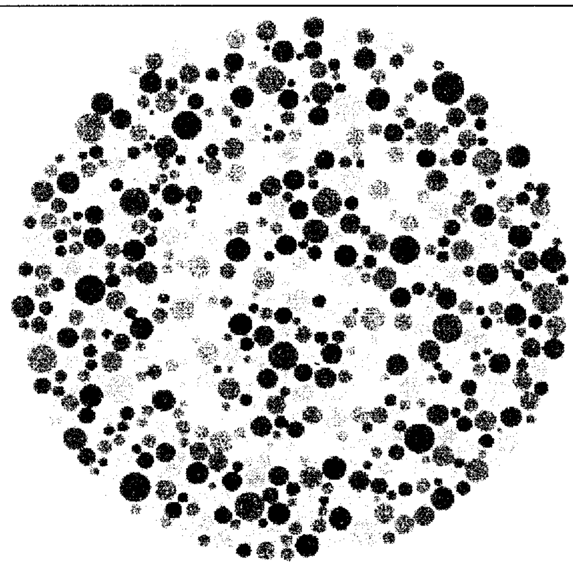
4. In the future, if you have to select, which display you will use?
   a) Sensitivity bar chart display
   b) Three-dimensional display

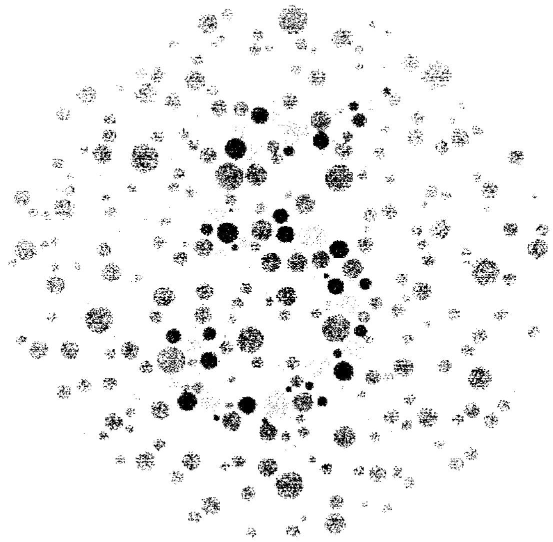
5.

[redacted]	1. Strongly disagree	2. Partly disagree	3. Neither agree nor disagree	4. Partly agree	5. Strongly agree
1. I found the 3D display was easier to understand than the 2D display for the combined effects of three cash flow elements	☐	☐	☐	☐	☐
2. I consider the 3D display help me to get better understanding of sensitivity analysis information than the 2D display	☐	☐	☐	☐	☐
3. I found the 3D display was easier to indicate reversal point or range (negative measure of merit, i.e., PW) than the 2D display	☐	☐	☐	☐	☐
4. From a managerial standpoint, the 3D display helped me made better decision than the 2D display	☐	☐	☐	☐	☐
5. I found the 3D display was easier to extract information that I needed than the 2D display	☐	☐	☐	☐	☐
6. I found the 3D display was more stressful to use than the 2D display	☐	☐	☐	☐	☐
7. I found the 3D display gave more motivation to use than the 2D display	☐	☐	☐	☐	☐

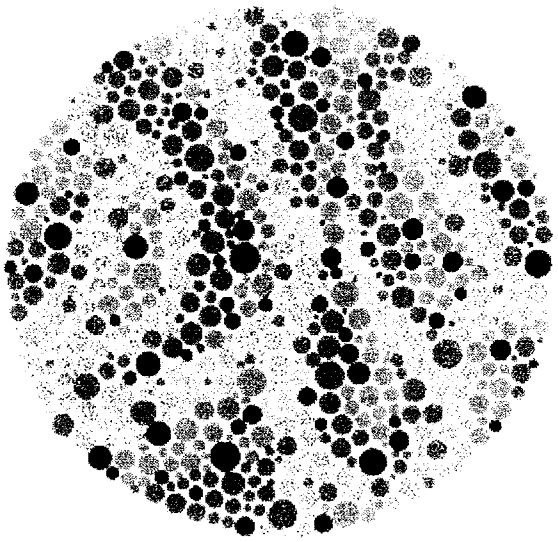
APPENDIX H: ISHIHARA TEST FOR COLOR BLINDNESS

	**Plate 1** Both normal and those with all color vision deficiencies should read the number 12.
	**Plate 2** Those with normal color vision should read the number 8. Those with red-green color vision deficiencies should read the number 3. Total color blindness should not be able to read any numeral.

	**Plate 4** Normal color vision should read the number 5. Red-Green color deficiencies should read the number 2. Total color blindness should not be able to read any numeral.
	**Plate 8** Normal color vision should read the number 6. The majority of those with color vision deficiencies cannot read this number or will read it incorrectly.

<table>
<tr><td></td><td>Plate 10

Normal color vision should read the number 5.

Those with color vision deficiencies will not read the number or read it incorrectly.</td></tr>
<tr><td></td><td>Plate 14

Normal color vision and those with total color blindness should not be able to read any number.

The majority of those with red-green deficiencies should read the number 5.</td></tr>
</table>

APPENDIX I: EXAMPLE OF DATA

The best (most likely) cash-flow estimates for a new engineering project are as follows:

Capital investment, P	$11,500
Revenues/year	$5,000
Expenses/year	$2,000
Market value, MV	$1,000
Useful life, N	6 years

Because of the new technology involves, it is desired to investigate the combined effects of three factors (*P, A, and N*) on the PW over a range of ± 40% changes in the estimates for (a) capital investment, (b) annual net cash flow, and (c) useful life. MARR = 10% per year.

Project Factor (Variable)	**Deviation Range**	**Best Estimate**	**Range Estimate**	
			Minimum	**Maximum**
Capital investment, P	-40% to +40%	$11,500	$6,900	$16,100
Annual net cash flow, A	-40% to +40%	$3,000	$1,800	$4,200
Useful life, N	-40% to +40%	6 years	3.6 years	8.4 years

No.	**± 40% of P**	**± 40% of A**	**± 40% of N**	**PW (10%)**
1	-40%	-40%	-40%	-962
2	-40%	-40%	-20%	341
3	-40%	-40%	0%	1504
4	-40%	-40%	20%	2541
5	-40%	-40%	40%	3466
6	-40%	-20%	-40%	780
7	-40%	-20%	-20%	2544
8	-40%	-20%	0%	4117
9	-40%	-20%	20%	5520
10	-40%	-20%	40%	6772
11	-40%	0%	-40%	2523
12	-40%	0%	-20%	4747
13	-40%	0%	0%	6730
14	-40%	0%	20%	8499
15	-40%	0%	40%	10077
16	-40%	20%	-40%	4266
17	-40%	20%	-20%	6950

18	-40%	20%	0%	9343
19	-40%	20%	20%	11479
20	-40%	20%	40%	13383
21	-40%	40%	-40%	6008
22	-40%	40%	-20%	9152
23	-40%	40%	0%	11957
24	-40%	40%	20%	14458
25	-40%	40%	40%	16689
26	-20%	-40%	-40%	-3262
27	-20%	-40%	-20%	-1959
28	-20%	-40%	0%	-796
29	-20%	-40%	20%	241
30	-20%	-40%	40%	1166
31	-20%	-20%	-40%	-1520
32	-20%	-20%	-20%	244
33	-20%	-20%	0%	1817
34	-20%	-20%	20%	3220
35	-20%	-20%	40%	4472
36	-20%	0%	-40%	223
37	-20%	0%	-20%	2447
38	-20%	0%	0%	4430
39	-20%	0%	20%	6199
40	-20%	0%	40%	7777
41	-20%	20%	-40%	1966
42	-20%	20%	-20%	4650
43	-20%	20%	0%	7043
44	-20%	20%	20%	9179
45	-20%	20%	40%	11083
46	-20%	40%	-40%	3708
47	-20%	40%	-20%	6852
48	-20%	40%	0%	9657
49	-20%	40%	20%	12158
50	-20%	40%	40%	14389
51	0%	-40%	-40%	-5562
52	0%	-40%	-20%	-4259
53	0%	-40%	0%	-3096
54	0%	-40%	20%	-2059
55	0%	-40%	40%	-1134
56	0%	-20%	-40%	-3820
57	0%	-20%	-20%	-2056
58	0%	-20%	0%	-483
59	0%	-20%	20%	920
60	0%	-20%	40%	2172

61	0%	0%	-40%	-2077
62	0%	0%	-20%	147
63	0%	0%	0%	2130
64	0%	0%	20%	3899
65	0%	0%	40%	5477
66	0%	20%	-40%	-334
67	0%	20%	-20%	2350
68	0%	20%	0%	4743
69	0%	20%	20%	6879
70	0%	20%	40%	8783
71	0%	40%	-40%	1408
72	0%	40%	-20%	4552
73	0%	40%	0%	7357
74	0%	40%	20%	9858
75	0%	40%	40%	12089
76	20%	-40%	-40%	-7862
77	20%	-40%	-20%	-6559
78	20%	-40%	0%	-5396
79	20%	-40%	20%	-4359
80	20%	-40%	40%	-3434
81	20%	-20%	-40%	-6120
82	20%	-20%	-20%	-4356
83	20%	-20%	0%	-2783
84	20%	-20%	20%	-1380
85	20%	-20%	40%	-128
86	20%	0%	-40%	-4377
87	20%	0%	-20%	-2153
88	20%	0%	0%	-170
89	20%	0%	20%	1599
90	20%	0%	40%	3177
91	20%	20%	-40%	-2634
92	20%	20%	-20%	50
93	20%	20%	0%	2443
94	20%	20%	20%	4579
95	20%	20%	40%	6483
96	20%	40%	-40%	-892
97	20%	40%	-20%	2252
98	20%	40%	0%	5057
99	20%	40%	20%	7558
100	20%	40%	40%	9789
101	40%	-40%	-40%	-10162
102	40%	-40%	-20%	-8859
103	40%	-40%	0%	-7696

104	40%	-40%	20%	-6659
105	40%	-40%	40%	-5734
106	40%	-20%	-40%	-8420
107	40%	-20%	-20%	-6656
108	40%	-20%	0%	-5083
109	40%	-20%	20%	-3680
110	40%	-20%	40%	-2428
111	40%	0%	-40%	-6677
112	40%	0%	-20%	-4453
113	40%	0%	0%	-2470
114	40%	0%	20%	-701
115	40%	0%	40%	877
116	40%	20%	-40%	-4934
117	40%	20%	-20%	-2250
118	40%	20%	0%	143
119	40%	20%	20%	2279
120	40%	20%	40%	4183
121	40%	40%	-40%	-3192
122	40%	40%	-20%	-48
123	40%	40%	0%	2757
124	40%	40%	20%	5258
125	40%	40%	40%	7489

APPENDIX J: COLOR SCALE

Magenta color scale				Heated-Object color scale			
Color #	**R**	**G**	**B**	**Color #**	**R**	**G**	**B**
1	0	0	0	1	0	0	0
2	40	0	0	2	35	0	0
3	56	0	4	3	52	0	0
4	61	0	9	4	60	0	0
5	64	0	12	5	63	1	0
6	66	0	14	6	64	2	0
7	69	0	17	7	68	5	0
8	73	0	20	8	69	6	0
9	74	0	22	9	72	8	0
10	78	0	25	10	74	10	0
11	79	0	27	11	77	12	0
12	83	0	30	12	78	14	0
13	85	0	31	13	81	16	0
14	86	0	33	14	83	17	0
15	90	0	36	15	85	19	0
16	91	0	38	16	86	20	0
17	93	0	39	17	89	22	0
18	95	0	41	18	91	24	0
19	96	0	43	19	92	25	0
20	100	0	46	20	94	26	0
21	102	0	47	21	95	28	0
22	103	0	49	22	98	30	0
23	105	0	51	23	100	31	0
24	107	0	52	24	102	33	0
25	108	0	54	25	103	34	0
26	110	0	55	26	105	35	0
27	112	0	57	27	106	36	0
28	112	0	57	28	108	38	0
29	113	0	58	29	109	39	0
30	115	0	60	30	111	40	0
31	117	0	62	31	112	42	0
32	119	0	63	32	114	43	0
33	120	0	65	33	115	44	0
34	122	0	66	34	117	45	0
35	124	0	68	35	119	47	0
36	125	0	70	36	119	47	0
37	127	0	71	37	120	48	0
38	129	0	73	38	122	49	0
39	129	0	73	39	123	51	0
40	130	0	74	40	125	52	0

41	132	0	76	41	125	52	0
42	134	0	78	42	126	53	0
43	136	0	79	43	128	54	0
44	137	0	81	44	129	56	0
45	139	0	82	45	129	56	0
46	141	0	84	46	131	57	0
47	142	0	86	47	132	58	0
48	144	0	87	48	134	59	0
49	146	0	89	49	134	59	0
50	147	0	90	50	136	61	0
51	149	0	92	51	137	62	0
52	151	0	94	52	137	62	0
53	151	0	94	53	139	63	0
54	153	0	95	54	139	63	0
55	154	0	97	55	140	65	0
56	156	0	98	56	142	66	0
57	158	0	100	57	142	66	0
58	159	0	102	58	143	67	0
59	161	0	103	59	143	67	0
60	163	0	105	60	145	68	0
61	164	0	106	61	145	68	0
62	166	0	108	62	146	70	0
63	168	0	109	63	146	70	0
64	170	0	111	64	148	71	0
65	171	0	113	65	148	71	0
66	173	0	114	66	149	72	0
67	175	0	116	67	149	72	0
68	176	0	117	68	151	73	0
69	178	0	119	69	151	73	0
70	180	0	121	70	153	75	0
71	180	0	121	71	153	75	0
72	181	0	122	72	154	76	0
73	183	0	124	73	154	76	0
74	185	0	125	74	154	76	0
75	187	0	127	75	156	77	0
76	188	0	129	76	156	77	0
77	190	0	130	77	157	79	0
78	192	0	132	78	157	79	0
79	193	0	133	79	159	80	0
80	195	0	135	80	159	80	0
81	197	0	137	81	159	80	0
82	198	0	138	82	160	81	0
83	200	0	140	83	160	81	0

84	202	0	141	84	162	82	0
85	204	0	143	85	162	82	0
86	204	0	143	86	163	84	0
87	205	0	145	87	163	84	0
88	207	0	146	88	165	85	0
89	209	0	148	89	165	85	0
90	210	0	149	90	166	86	0
91	212	0	151	91	166	86	0
92	214	0	153	92	166	86	0
93	215	0	154	93	168	87	0
94	217	0	156	94	168	87	0
95	219	0	157	95	170	89	0
96	221	0	159	96	170	89	0
97	222	0	160	97	171	90	0
98	222	0	160	98	171	90	0
99	224	0	162	99	173	91	0
100	226	0	164	100	173	91	0
101	227	0	165	101	174	93	0
102	229	0	167	102	174	93	0
103	231	0	168	103	176	94	0
104	232	0	170	104	176	94	0
105	234	0	172	105	177	95	0
106	236	0	173	106	177	95	0
107	238	0	175	107	179	96	0
108	238	0	175	108	179	96	0
109	239	0	176	109	180	98	0
110	241	0	178	110	182	99	0
111	243	0	180	111	182	99	0
112	244	0	181	112	183	100	0
113	246	0	183	113	183	100	0
114	248	2	184	114	185	102	0
115	249	4	186	115	185	102	0
116	249	4	186	116	187	103	0
117	249	4	186	117	187	103	0
118	251	6	188	118	188	104	0
119	251	6	188	119	188	104	0
120	253	9	189	120	190	105	0
121	253	9	189	121	191	107	0
122	255	11	191	122	191	107	0
123	255	11	191	123	193	108	0
124	255	13	192	124	193	108	0
125	255	13	192	125	194	109	0
126	255	13	192	126	196	110	0

127	255	16	194	127	196	110	0
128	255	18	196	128	197	112	0
129	255	20	197	129	197	112	0
130	255	20	197	130	199	113	0
131	255	23	199	131	200	114	0
132	255	25	200	132	200	114	0
133	255	27	202	133	202	116	0
134	255	30	204	134	202	116	0
135	255	32	205	135	204	117	0
136	255	34	207	136	205	118	0
137	255	37	208	137	205	118	0
138	255	37	208	138	207	119	0
139	255	39	210	139	208	121	0
140	255	41	211	140	208	121	0
141	255	44	213	141	210	122	0
142	255	46	215	142	211	123	0
143	255	48	216	143	211	123	0
144	255	51	218	144	213	124	0
145	255	53	219	145	214	126	0
146	255	53	219	146	214	126	0
147	255	55	221	147	216	127	0
148	255	57	223	148	217	128	0
149	255	60	224	149	217	128	0
150	255	62	226	150	219	130	0
151	255	64	227	151	221	131	0
152	255	67	229	152	221	131	0
153	255	67	229	153	222	132	0
154	255	69	231	154	224	133	0
155	255	71	232	155	224	133	0
156	255	74	234	156	225	135	0
157	255	76	235	157	227	136	0
158	255	78	237	158	227	136	0
159	255	81	239	159	228	137	0
160	255	81	239	160	230	138	0
161	255	83	240	161	230	138	0
162	255	85	242	162	231	140	0
163	255	88	243	163	233	141	0
164	255	90	245	164	233	141	0
165	255	92	247	165	234	142	0
166	255	95	248	166	236	144	0
167	255	95	248	167	236	144	0
168	255	97	250	168	238	145	0
169	255	99	251	169	239	146	0

170	255	102	253	170	241	147	0
171	255	104	255	171	241	147	0
172	255	106	255	172	242	149	0
173	255	106	255	173	244	150	0
174	255	108	255	174	244	150	0
175	255	111	255	175	245	151	0
176	255	113	255	176	247	153	0
177	255	115	255	177	247	153	0
178	255	115	255	178	248	154	0
179	255	118	255	179	250	155	0
180	255	120	255	180	251	156	0
181	255	122	255	181	251	156	0
182	255	122	255	182	253	158	0
183	255	125	255	183	255	159	0
184	255	127	255	184	255	159	0
185	255	129	255	185	255	160	0
186	255	129	255	186	255	161	0
187	255	132	255	187	255	163	0
188	255	134	255	188	255	163	0
189	255	136	255	189	255	164	0
190	255	136	255	190	255	165	0
191	255	139	255	191	255	167	0
192	255	141	255	192	255	167	0
193	255	143	255	193	255	168	0
194	255	143	255	194	255	169	0
195	255	146	255	195	255	169	0
196	255	148	255	196	255	170	0
197	255	150	255	197	255	172	0
198	255	150	255	198	255	173	0
199	255	153	255	199	255	173	0
200	255	155	255	200	255	174	0
201	255	155	255	201	255	175	0
202	255	157	255	202	255	177	0
203	255	159	255	203	255	178	0
204	255	159	255	204	255	179	0
205	255	162	255	205	255	181	0
206	255	164	255	206	255	181	0
207	255	164	255	207	255	182	0
208	255	166	255	208	255	183	0
209	255	169	255	209	255	184	0
210	255	171	255	210	255	187	7
211	255	171	255	211	255	188	10
212	255	173	255	212	255	189	14

213	255	176	255	213	255	191	18
214	255	176	255	214	255	192	21
215	255	178	255	215	255	193	25
216	255	180	255	216	255	195	29
217	255	180	255	217	255	197	36
218	255	183	255	218	255	198	40
219	255	185	255	219	255	200	43
220	255	185	255	220	255	202	51
221	255	187	255	221	255	204	54
222	255	190	255	222	255	206	61
223	255	190	255	223	255	207	65
224	255	192	255	224	255	210	72
225	255	194	255	225	255	211	76
226	255	197	255	226	255	214	83
227	255	197	255	227	255	216	91
228	255	199	255	228	255	219	98
229	255	201	255	229	255	221	105
230	255	204	255	230	255	223	109
231	255	204	255	231	255	225	116
232	255	206	255	232	255	228	123
233	255	208	255	233	255	232	134
234	255	210	255	234	255	234	142
235	255	210	255	235	255	237	149
236	255	213	255	236	255	239	156
237	255	215	255	237	255	240	160
238	255	217	255	238	255	243	167
239	255	217	255	239	255	246	174
240	255	220	255	240	255	248	182
241	255	222	255	241	255	249	185
242	255	224	255	242	255	252	193
243	255	227	255	243	255	253	196
244	255	229	255	244	255	255	204
245	255	229	255	245	255	255	207
246	255	231	255	246	255	255	211
247	255	234	255	247	255	255	218
248	255	236	255	248	255	255	222
249	255	238	255	249	255	255	225
250	255	241	255	250	255	255	229
251	255	243	255	251	255	255	233
252	255	243	255	252	255	255	236
253	255	245	255	253	255	255	240
254	255	248	255	254	255	255	244
255	255	250	255	255	255	255	247

256	255	255	255	256	255	255	255

Orange-Yellow color scale				Magenta-Orange-Yellow color scale			
Color #	**R**	**G**	**B**	**Color #**	**R**	**G**	**B**
1	0	0	0	1	20	0	0
2	40	0	0	2	59	7	0
3	56	4	0	3	65	13	0
4	61	9	0	4	71	19	0
5	64	12	0	5	76	24	0
6	66	14	0	6	81	29	0
7	69	17	0	7	86	32	0
8	73	20	0	8	91	37	0
9	74	22	0	9	94	40	0
10	78	25	0	10	98	45	0
11	79	27	0	11	103	48	0
12	83	30	0	12	106	52	0
13	85	31	0	13	109	55	0
14	86	33	0	14	112	57	0
15	90	36	0	15	114	59	0
16	91	38	0	16	118	63	0
17	93	39	0	17	121	66	0
18	95	41	0	18	125	69	0
19	96	43	0	19	128	72	0
20	100	46	0	20	130	74	0
21	102	47	0	21	133	77	0
22	103	49	0	22	137	80	0
23	105	51	0	23	140	83	0
24	107	52	0	24	143	87	0
25	108	54	0	25	147	90	0
26	110	55	0	26	150	93	0
27	112	57	0	27	152	95	0
28	112	57	0	28	155	98	0
29	113	58	0	29	159	101	0
30	115	60	0	30	162	104	0
31	117	62	0	31	165	107	0
32	119	63	0	32	169	110	0
33	120	65	0	33	172	114	0
34	122	66	0	34	176	117	0
35	124	68	0	35	179	120	0
36	125	70	0	36	181	122	0

37	127	71	0	37	184	125	0
38	129	73	0	38	188	128	0
39	129	73	0	39	191	131	0
40	130	74	0	40	194	134	0
41	132	76	0	41	198	138	0
42	134	78	0	42	201	141	0
43	136	79	0	43	204	143	0
44	137	81	0	44	206	146	0
45	139	82	0	45	210	149	0
46	141	84	0	46	213	152	0
47	142	86	0	47	216	155	0
48	144	87	0	48	220	158	0
49	146	89	0	49	222	160	0
50	147	90	0	50	225	163	0
51	149	92	0	51	228	166	0
52	151	94	0	52	232	169	0
53	151	94	0	53	235	173	0
54	153	95	0	54	238	175	0
55	154	97	0	55	240	177	0
56	156	98	0	56	244	181	0
57	158	100	0	57	247	184	1
58	159	102	0	58	249	186	4
59	161	103	0	59	250	187	5
60	163	105	0	60	252	189	8
61	164	106	0	61	254	190	10
62	166	108	0	62	255	192	12
63	168	109	0	63	255	192	13
64	170	111	0	64	255	195	17
65	171	113	0	65	255	197	20
66	173	114	0	66	255	200	24
67	175	116	0	67	255	203	29
68	176	117	0	68	255	206	33
69	178	119	0	69	255	208	37
70	180	121	0	70	255	211	40
71	180	121	0	71	255	214	45
72	181	122	0	72	255	217	50
73	183	124	0	73	255	219	53
74	185	125	0	74	255	222	56
75	187	127	0	75	255	225	61
76	188	129	0	76	255	228	66
77	190	130	0	77	255	230	68
78	192	132	0	78	255	233	73
79	193	133	0	79	255	236	77

80	195	135	0	80	255	239	81
81	197	137	0	81	255	241	84
82	198	138	0	82	255	244	89
83	200	140	0	83	255	248	94
84	202	141	0	84	255	249	96
85	204	143	0	85	255	252	101
86	204	143	0	86	255	255	105
87	205	145	0	87	255	255	107
88	207	146	0	88	255	255	112
89	209	148	0	89	255	255	115
90	210	149	0	90	255	255	119
91	212	151	0	91	255	255	122
92	214	153	0	92	255	255	126
93	215	154	0	93	255	255	129
94	217	156	0	94	255	255	133
95	219	157	0	95	255	255	136
96	221	159	0	96	255	255	140
97	222	160	0	97	255	255	143
98	222	160	0	98	255	255	147
99	224	162	0	99	255	255	150
100	226	164	0	100	255	255	154
101	227	165	0	101	255	255	156
102	229	167	0	102	255	255	159
103	231	168	0	103	255	255	163
104	232	170	0	104	255	255	165
105	234	172	0	105	255	255	170
106	236	173	0	106	255	255	172
107	238	175	0	107	255	255	176
108	238	175	0	108	255	255	179
109	239	176	0	109	255	255	182
110	241	178	0	110	255	255	185
111	243	180	0	111	255	255	189
112	244	181	0	112	255	255	191
113	246	183	0	113	255	255	196
114	248	184	2	114	255	255	198
115	249	186	4	115	255	255	203
116	249	186	4	116	255	255	205
117	249	186	4	117	255	255	209
118	251	188	6	118	255	255	212
119	251	188	6	119	255	255	216
120	253	189	9	120	255	255	219
121	253	189	9	121	255	255	223
122	255	191	11	122	255	255	228

123	255	191	11	123	255	255	230
124	255	192	13	124	255	255	235
125	255	192	13	125	255	255	240
126	255	192	13	126	255	255	243
127	255	194	16	127	255	255	247
128	255	196	18	128	255	255	253
129	255	197	20	129	255	253	255
130	255	197	20	130	255	247	255
131	255	199	23	131	255	243	255
132	255	200	25	132	255	240	255
133	255	202	27	133	255	235	255
134	255	204	30	134	255	230	255
135	255	205	32	135	255	228	255
136	255	207	34	136	255	223	255
137	255	208	37	137	255	219	255
138	255	208	37	138	255	216	255
139	255	210	39	139	255	212	255
140	255	211	41	140	255	209	255
141	255	213	44	141	255	205	255
142	255	215	46	142	255	203	255
143	255	216	48	143	255	198	255
144	255	218	51	144	255	196	255
145	255	219	53	145	255	191	255
146	255	219	53	146	255	189	255
147	255	221	55	147	255	185	255
148	255	223	57	148	255	182	255
149	255	224	60	149	255	179	255
150	255	226	62	150	255	176	255
151	255	227	64	151	255	172	255
152	255	229	67	152	255	170	255
153	255	229	67	153	255	165	255
154	255	231	69	154	255	163	255
155	255	232	71	155	255	159	255
156	255	234	74	156	255	156	255
157	255	235	76	157	255	154	255
158	255	237	78	158	255	150	255
159	255	239	81	159	255	147	255
160	255	239	81	160	255	143	255
161	255	240	83	161	255	140	255
162	255	242	85	162	255	136	255
163	255	243	88	163	255	133	255
164	255	245	90	164	255	129	255
165	255	247	92	165	255	126	255

166	255	248	95	166	255	122	255
167	255	248	95	167	255	119	255
168	255	250	97	168	255	115	255
169	255	251	99	169	255	112	255
170	255	253	102	170	255	107	255
171	255	255	104	171	255	105	255
172	255	255	106	172	255	101	252
173	255	255	106	173	255	96	249
174	255	255	108	174	255	94	248
175	255	255	111	175	255	89	244
176	255	255	113	176	255	84	241
177	255	255	115	177	255	81	239
178	255	255	115	178	255	77	236
179	255	255	118	179	255	73	233
180	255	255	120	180	255	68	230
181	255	255	122	181	255	66	228
182	255	255	122	182	255	61	225
183	255	255	125	183	255	56	222
184	255	255	127	184	255	53	219
185	255	255	129	185	255	50	217
186	255	255	129	186	255	45	214
187	255	255	132	187	255	40	211
188	255	255	134	188	255	37	208
189	255	255	136	189	255	33	206
190	255	255	136	190	255	29	203
191	255	255	139	191	255	24	200
192	255	255	141	192	255	20	197
193	255	255	143	193	255	17	195
194	255	255	143	194	255	13	192
195	255	255	146	195	255	12	192
196	255	255	148	196	254	10	190
197	255	255	150	197	252	8	189
198	255	255	150	198	250	5	187
199	255	255	153	199	249	4	186
200	255	255	155	200	247	1	184
201	255	255	155	201	244	0	181
202	255	255	157	202	240	0	177
203	255	255	159	203	238	0	175
204	255	255	159	204	235	0	173
205	255	255	162	205	232	0	169
206	255	255	164	206	228	0	166
207	255	255	164	207	225	0	163
208	255	255	166	208	222	0	160

209	255	255	169	209	220	0	158
210	255	255	171	210	216	0	155
211	255	255	171	211	213	0	152
212	255	255	173	212	210	0	149
213	255	255	176	213	206	0	146
214	255	255	176	214	204	0	143
215	255	255	178	215	201	0	141
216	255	255	180	216	198	0	138
217	255	255	180	217	194	0	134
218	255	255	183	218	191	0	131
219	255	255	185	219	188	0	128
220	255	255	185	220	184	0	125
221	255	255	187	221	181	0	122
222	255	255	190	222	179	0	120
223	255	255	190	223	176	0	117
224	255	255	192	224	172	0	114
225	255	255	194	225	169	0	110
226	255	255	197	226	165	0	107
227	255	255	197	227	162	0	104
228	255	255	199	228	159	0	101
229	255	255	201	229	155	0	98
230	255	255	204	230	152	0	95
231	255	255	204	231	150	0	93
232	255	255	206	232	147	0	90
233	255	255	208	233	143	0	87
234	255	255	210	234	140	0	83
235	255	255	210	235	137	0	80
236	255	255	213	236	133	0	77
237	255	255	215	237	130	0	74
238	255	255	217	238	128	0	72
239	255	255	217	239	125	0	69
240	255	255	220	240	121	0	66
241	255	255	222	241	118	0	63
242	255	255	224	242	114	0	59
243	255	255	227	243	112	0	57
244	255	255	229	244	109	0	55
245	255	255	229	245	106	0	52
246	255	255	231	246	103	0	48
247	255	255	234	247	98	0	45
248	255	255	236	248	94	0	40
249	255	255	238	249	91	0	37
250	255	255	241	250	86	0	32
251	255	255	243	251	81	0	29

252	255	255	243	252	76	0	24
253	255	255	245	253	71	0	19
254	255	255	248	254	65	0	13
255	255	255	250	255	59	0	7
256	255	255	255	256	20	0	0

Gray scale				**Gray-Magenta color scale**			
Color #	**R**	**G**	**B**	**Color #**	**R**	**G**	**B**
1	0	0	0	1	254	254	254
2	0	0	0	2	252	252	252
3	0	0	0	3	249	249	249
4	0	0	0	4	243	243	243
5	0	0	0	5	240	240	240
6	0	0	0	6	234	234	234
7	0	0	0	7	227	227	227
8	1	1	1	8	221	221	221
9	1	1	1	9	218	218	218
10	1	1	1	10	212	212	212
11	1	1	1	11	207	207	207
12	1	1	1	12	201	201	201
13	1	1	1	13	198	198	198
14	1	1	1	14	195	195	195
15	1	1	1	15	193	193	193
16	1	1	1	16	190	190	190
17	2	2	2	17	185	185	185
18	2	2	2	18	179	179	179
19	2	2	2	19	174	174	174
20	2	2	2	20	169	169	169
21	2	2	2	21	167	167	167
22	2	2	2	22	162	162	162
23	2	2	2	23	157	157	157
24	3	3	3	24	154	154	154
25	3	3	3	25	150	150	150
26	3	3	3	26	147	147	147
27	3	3	3	27	145	145	145
28	3	3	3	28	143	143	143
29	3	3	3	29	139	139	139
30	3	3	3	30	134	134	134
31	4	4	4	31	130	130	130
32	4	4	4	32	128	128	128

33	4	4	4	33	124	124	124
34	4	4	4	34	120	120	120
35	4	4	4	35	116	116	116
36	5	5	5	36	114	114	114
37	5	5	5	37	110	110	110
38	5	5	5	38	108	108	108
39	5	5	5	39	107	107	107
40	5	5	5	40	104	104	104
41	6	6	6	41	101	101	101
42	6	6	6	42	97	97	97
43	6	6	6	43	94	94	94
44	6	6	6	44	93	93	93
45	6	6	6	45	89	89	89
46	7	7	7	46	86	86	86
47	7	7	7	47	84	84	84
48	7	7	7	48	81	81	81
49	7	7	7	49	78	78	78
50	7	7	7	50	76	76	76
51	8	8	8	51	76	76	76
52	8	8	8	52	74	74	74
53	9	9	9	53	71	71	71
54	9	9	9	54	68	68	68
55	9	9	9	55	67	67	67
56	9	9	9	56	64	64	64
57	10	10	10	57	61	61	61
58	10	10	10	58	59	59	59
59	10	10	10	59	58	58	58
60	10	10	10	60	55	55	55
61	10	10	10	61	53	53	53
62	11	11	11	62	52	52	52
63	11	11	11	63	51	51	51
64	12	12	12	64	49	49	49
65	12	12	12	65	47	47	47
66	12	12	12	66	46	46	46
67	13	13	13	67	46	46	46
68	13	13	13	68	44	44	44
69	14	14	14	69	42	42	42
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256	255	255	255	256	255	253	255

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