AN INVESTMENT ANALYSIS MODEL USING FUZZY SET THEORY

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(ABSTRACT)

Traditional methods for evaluating investments in state-of-the-art technology are sometimes found lacking in providing equitable recommendations for project selection. The major cause for this is the inability of these methods to handle adequately uncertainty and imprecision, and account for every aspect of the project, economic and non-economic, tangible and intangible. Fuzzy set theory provides an alternative to probability theory for handling uncertainty, while at the same time being able to handle imprecision. It also provides a means of closing the gap between the human thought process and the computer, by enabling the establishment of linguistic quantifiers to describe intangible attributes. Fuzzy set theory has been used successfully in other fields for aiding the decision making process.

The intention of this research has been the application of fuzzy set theory to aid investment decision making. The research has led to the development of a structured model, based on theoretical algorithms developed by Buckley and others. The model looks at a project from three different standpoints -- economic, operational, and strategic. It provides recommendations by means of five different values for the project desirability, and results of two sensitivity analyses. The model is tested on a hypothetical case study. The end result is a model that can be used as a basis for promising future development of investment analysis models.

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Lastly, to my constant source of strength, my best friend, my wife I would like to say one thing -- this is for you.

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1. Introduction

1.1 Background

The capital investment decision is one of the most crucial ones that a manager must make. Historically, economic justification techniques alone have mostly been used to assess the viability of capital equipment expenditures. However, the situation has now changed significantly with the advent of today's advanced manufacturing systems. These systems abound in technical, as well as monetary and non-monetary complexities. It is therefore entirely possible that a project that does not completely satisfy the financial hurdles set by the firm shows up as an attractive alternative when seen in the light of both its monetary as well as non-monetary benefits. Consequently, it is imperative that projects be judged on both grounds to permit a fair evaluation. This makes the task as complex as it is critical.

Additionally, the decision making environment is one that is clouded with uncertainty. This complicates matters further. Few, if any, inputs to the decision problem are completely expected or known. These uncertainties combined result in project risk, and yet must be handled in order to endorse projects within acceptable risk limits. Over the years, probability theory, with the help of computers, has been used quite extensively for handling uncertainty in decision making. However, the results, even though promising, have led more and more to the awareness that not all the uncertainty can be modelled stochastically [48]. The necessity of being able to represent human reasoning in the decision model has been increasingly felt. This global or parallel reasoning, as opposed to logical reckoning, is fuzzy, non-quantitative, imprecise and as such incapable of being represented by probability distributions [12]. It is subtle, rarely ever binary, and therefore prevents effective communication between humans and the most powerful of computers with formal languages, or even with natural languages. Computers at the same time are much more efficient in information processing than people. Therefore, a human-machine interface that is capable of translating human reasoning and thought into machine readable language is essentially the last frontier in the science of decision support models.

The theory of Fuzzy Sets, first proposed by Zadeh in 1965 [52], attempts to cross this frontier. It is based on the notion of weighted membership. An element may then belong more or less to a subset. The theory allows for the structuring of all that is separated by considerations that are a little precise, such as thought, language, and perception among decision makers. It has been used very successfully in other areas, and the intention here has been to apply it to the economic and multi-attribute evaluation process for today's advanced manufacturing systems.

1.2 Problem Statement

The traditional economic evaluation procedures which test the viability of projects are found lacking in presenting fair judgments, especially on today's highly advanced manufacturing systems. This is because they do not account for many attributes that do not lie in the area of direct financial gain, but are nevertheless important advantages and disadvantages connected with these systems. At the same time, the inherent uncertainty associated with the decision-making environment is not being fully accounted for by probability theory.

1.3 Research Objective

The objective of this research was to develop a model that in the future may lead to the evolution of a comprehensive decision support system, to be implemented on a desktop microcomputer and that will help the manager make better informed capital investment decisions. Based on fuzzy set theory, the model has the capability to do the following:

1) Perform an economic evaluation of the project, taking into account the prevalent imprecision and uncertainty, if any, as one of the primary tasks in the decision support environment.

2) Interrogate the user to identify other attributes that may be relevant to the decision-making process.

3) Interact with the user to identify which of these attributes may be defined numerically and whether they have an inherent imprecision attached to them.

4) Assimilate the data connected with each of these attributes and convert it into fuzzy number terms. This may be done by assigning membership functions to the various values for the data, through constant interaction with the user.

5) Interrogate the decision maker to determine any other attribute that needs to be considered, even though no quantitative value can yet be attached to it.

6) Interact with the user to determine the qualitative measure that is attached to these attributes. Convert the qualitative measure into fuzzy linguistic terms.

7) Interrogate the decision maker in a clear manner to determine preferences regarding attribute weights.

8) Use the information provided by the user to evaluate the given alternative and assign to it a fuzzy number or linguistic value, such that a comparison of different alternatives is then

possible by only comparing these values.

9) Provide the decision maker with the ability to go back and change the original preferences to see how the changes affect the results. In other words, provide the ability to perform a sensitivity analysis.

1.4 Assumptions

The development of the system is based on the following assumptions:

1) There is only one decision maker, so there is no necessity of the system being able to account for different preferences regarding any given proposal(s).
2) The system involves only single stage decisions.
3) The various projects being considered are not connected or interdependent.
4) Partial proposals may not be accepted.
5) There can be a maximum of eleven attributes per module attached to each proposal [15].
6) The attributes are preferentially independent.

1.5 Outline Of The Research

Chapter 2 presents a literature review of appropriate techniques, theories, and applications in the area of capital investment economic analysis, multi-attribute decision making, and the application of fuzzy set theory to these areas. Chapter 3 discusses the step-by-step development of the methodology that forms the basis of the mathematical model, while Chapter 4 discusses the computer model. Chapter 5 contains a hypothetical case study, the model results for it, and analysis of the results. Chapter 6 contains the conclusions and recommendations for further development. Definitions and proofs, the entire code, and a brief guide to implementing the computer model are contained in the appendices.

2. Literature Review

2.1 Introduction

A major hurdle in the adoption of today's new technologies is its economic justification. This is especially so because traditional justification methods do not take into account two vital factors that are essential to a sound investment decision. First, today's advanced systems have many advantages, such as shorter lead time, better quality, better customer satisfaction, etc., that may or may not be easily quantifiable, monetarily or otherwise [35]. Thus, depending on the individual system in consideration, it may or may not be a reasonable expectation that justification is possible on the traditional basis of cost reduction, improved profit, or capacity expansion. Second, the level of uncertainty that pervades the decision environment is so great today, that it simply must be taken into account, if realistic evaluations are to be achieved [5]. These uncertainties in fact are some of the major causes of the risk that is connected to the capital investment decision, so the higher the uncertainty the higher the risk. Consequently it is critical for the competitiveness and survival of a firm to account for an uncertain environment.

This uncertainty or imprecision, appears in the form of vagueness, i.e., ill defined, inexact, and doubtful data, and attributes that are given qualitative values that are fuzzy and difficult to pin down in quantitative terms. The present models, based on the theory of probability, are found lacking in being able to model this uncertainty and imprecision completely, nor are they able to incorporate the all important aspect of human reasoning. This leaves a wide gap that needs to be bridged, if decision support systems are truly expected to be more and more associated with the human thought process.

Significant research has been conducted in both these problem areas, and various models to tackle each of the two problems have been developed. However, the need is an integrated model that can formally account for the direct as well as indirect benefits of the projects at hand, while at the same time being capable of handling whatever uncertainty or imprecision that may be prevalent in these benefits. This research is a step towards the satisfaction of this need. What has been developed is a model for a multi-attribute decision-support system, based on fuzzy logic to model uncertainty, that will aid in the equitable evaluation of industrial projects.

This chapter presents a literature review that formed the basis for this research. It includes the theory that governs traditional evaluation techniques, the need for multi-attribute decision making, the present methodologies for handling uncertainty, the fuzzy set theory and its application to these areas. The number of articles and books on traditional economic evaluation and multi-attribute decision making that have been published are numerous. Even on the fuzzy set theory, which is a relatively new field, the literature available is extensive. It was therefore not possible to be able to incorporate each and every article or book's viewpoint. However, every attempt has been made to cover the views presented in articles and books that are considered landmarks in their fields. The overall intent has been to present those views that may be taken as representative of the viewpoints of a significant number of people.

2.2 Traditional Capital Investment Analysis Methods

According to Au and Au [1, page 12], "Investment may be defined as the commitment of resources to some economic activity in anticipation of greater returns or benefits in the future. In a strict economic sense, investment takes place only when natural resources are converted into capital assets such as the plant and other assets. Investment in new capital assets, whether in the private or public sector, is referred to as capital investment."

The most popular methods for investment analysis in use in industry today are payback period, net present worth (NPV) and internal rate of return (IRR). As far as the payback period method is concerned, experts have long since discounted it as an erroneous and inaccurate method of determining the viability of projects. However, its usage in industry is in sharp contrast to expert opinion. Surveys [19][26][36][41] show that a sizeable number of firms still use this method of evaluation. In 1978, Schall, Sundem, and Geijsbeck [41] reported that of 189 large U.S. firms surveyed, 86% used the discounted cash flow (DCF) methods, namely net present worth or internal rate of return; however, 83% of that group also used payback. Fotsch [17] determined in 1983 that the payback method is used by as many as 91% of the firms. Hodder [26], as part of a comparative evaluation of U.S. and Japanese techniques for investment evaluation, conducted a survey of Japanese industry. Interestingly, a significant majority of the Japanese firms used only slightly modified payback methodologies for their evaluation. The slight modification was that they did take the time value of money into account as well.

The question immediately arises -- if the method is considered inaccurate and erroneous, why is there such an overwhelming majority of firms still using the payback method ? According to Statman [43], one of the major reasons why this method is being used may lie in the conflict between the owners and the managers of the firm. He says that the owners of a firm would be indifferent between two proposals with the same risk-adjusted net present worth, even though one has a longer payback period, because the owners can sell their stock in the capital market at any time. However, a manager who may expect to stay with the firm for a period shorter than the economic life of the project, and whose compensation is linked to the annual cash flows from the projects, would prefer the project with the shorter payback period.

Weingartner's [49] explanation of the use of payback period is liquidity preference. He says that shorter payback periods allow the firm to utilize the funds on new projects earlier. Both these hypotheses can be challenged by alternate compensation schemes and capital resources respectively. Hodder [26] explains that the Japanese, in analyzing their proposals using these methods, place a great emphasis on verbal discussions on the desirability of the proposal between managers from different fields. This, in his opinion, compensates for the payback period procedures being inadequate in terms of comprehensive analysis. Tombari [46] calls both these methods screening techniques -- that is, techniques to provide a quick analysis to determine the absolutely undesirable projects from the more desirable ones. This in fact may be the reason why so many firms are using payback in conjunction with other more sophisticated methods.

The net present worth and internal rate of return methods take into account the time value of money and are generally the methods of choice in industry. These two methods have been the subject of substantial discussion over the past years. Critiques have included Gerwin [18], Gold [20], and Hayes [22] who have objected to these techniques having conceptual weaknesses and bias against long-term projects among other negative points. On the other hand Hodder and Riggs [25], for example, say that the techniques are technically sound, and the problem may well lie in the misapplication of these techniques to the problem in question.

However, one thing that is established is that both these methods for project evaluation may produce different rankings of competing investment projects [2][16]. Renshaw [37] and Soloman

[42] attribute the differences in the two methods to different implicit assumptions regarding the reinvestment of project cash flows, but do not seem to have a preference of one method over the other. Beaves [2] is in agreement with Soloman and Renshaw and has formulated two new indices, NPV* and ROR*, of which NPV and IRR taken in the conventional sense, are special cases. Grant, et. al. [21] argue against the use of reinvestment rates, saying that they can distort the attractiveness of the project. They advocate the use of the IRR index, because it is solely a function of the amounts and timing of a project's cash flow, and thus is the result of pure inseparable investment in that project. Beaves' [2] counter argument to that is that the IRR cannot assume that a project's intermediate cash flows cannot be reinvested, or that the reinvestment rate is zero. The use of the IRR index implies an assumption, therefore, that the intermediate cash flows are invested at a rate equal to the project's IRR. This assumption according to Beaves [2] cannot assure a fair comparison of projects with different IRR's. However, "reinvestment rate assumptions," according to Lohmann [33], are numerically, mathematically, and intuitively fallacious, but he too, does not advocate the use of any one method over the other. In a similar vein, Dudley [14] offers the following opinion:

> "The assumptions about reinvestment rates are implicit, unknowingly and by default, in the decision to use one or the other of the two criteria and not to make any explicit estimate of the possible return on reinvestment of intermediate cash flows received prior to the terminal date. The importance of this distinction lies in the fact that the erroneous belief implies that the problem is beyond the practical control of the analyst. ... In fact, ... the difficulty is easily handled by the analyst, if only he will recognize its existence and its cause."

According to White, Agee and Case [50], the primary reason for having different but equivalent measures of effectiveness for economic alternatives is differences in preferences in managers. George Taylor [45] however says that each method, be it present worth or the rate of return method, has it's own distinct advantages varying from situation to situation and recommends the use of both to reap the benefits from each of them. According to him, the net present worth method, for example, is unique in performing property valuation. It may also enhance graphic illustrations. At the same time, the rate of return method actually computes more than required for a mere selection between two alternatives; it places each investment in a position for laddering in a capital budgeting situation, something that the NPV cannot achieve directly.

Au and Au [1], on the other hand, state quite clearly that the rate of return method is cumbersome whether applied to the direct analysis of independent projects or to the incremental analysis of mutually exclusive alternatives. They say that the popularity of the method can only be attributed to the ignorance of the shortcomings of the method. The method, they say, does not take into account the differences in capital intensities at various time periods of the planning horizon, nor does it generally reflect the investment rate of any early year returns. It is therefore not necessarily an accurate measure of the profit potential of the project. The NPV method is the most direct method of analysis, and in their opinion should therefore be the method used. Secondary measures such as the benefit-cost ratio, the overall rate of return, the internal rate of return, or the payback period may then be calculated in a straightforward manner. Canada, Sullivan and Orr [10] are in agreement with the conclusions of Au and Au [1].

2.3 Current Methods for Handling Uncertainty and Risk

Sensitivity analysis has been used to some extent to model uncertainty in capital investment analysis by observing the changes in the desirability criteria in relation to changes in the various inputs to the analytical procedure, but it's acceptance and use as a sound method of modelling uncertainty has been limited at best [5][16][50]. The use of discounted cash flow techniques, like NPV and IRR discussed above, with risk-adjusted hurdle rates is also one of the methods used today. However, the two methods mostly used today for handling risk and uncertainty in capital investment analysis are the Monte Carlo simulation method and closed-form analysis method, and both are based on probability theory [5].

The Monte Carlo simulation method really consists of describing each attribute in terms of probability distributions, using computer capability to draw random variates from these distributions, calculating the respective economic criteria from these random values, repeating this procedure several times and then providing a statistical analysis of the computations [23][44]. The closed form analysis method usually consists of modelling cash flow streams by describing their functional changes over time and the variational character of parameters of these flows, and then computing the important statistics of the evaluation criteria being used [5] [24]. The simulation method and closed form analysis have their advantages and their disadvantages.

Buck [5] points out that in the simulation, the primary limitation is in one's modelling ability and not in inherent mathematical or statistical properties, since the relationships between the various probabilistic relationships are given in the modelling phase, and the computations are directly executed in the computer. The closed-form analysis, according to him, is completely based on formulae that have mathematical limitations and as such, this form of analysis is only efficient when these limitations do not appear too unreasonable. At the same time, he also points out that the simulation approach requires considerable computer capability and typically more time from the analyst. In this respect, Sullivan and Orr [44] not only endorse what Buck [5] says but bring out an additional limitation of the simulation method. They say that there is always the danger of the analyst being unaware of hidden assumptions in the computer program which receives model information inputs and processes the data. This danger is less likely with the closed-form analysis method, in which the assumptions, if any, need not be hidden.

2.4 The Need for Expanding These Methods

There has been a growing feeling in industrial and academic circles that while the traditional methods of evaluation might give satisfactory results in some situations, in most situations they prove to be insufficient. While some experts feel that this is due mostly to incorrect application of the methods [25], a significant number of them [8][17][20]29][30][35] think that pure economic procedures cannot give a fair evaluation of today's advanced manufacturing systems. These systems, according to them, have many other advantages that cannot be quantified in monetary terms (or sometimes even non-monetary terms).

Varney, Sullivan and Cochran [47] say that the discounted cash flow techniques are best suited to measure the attainment of short-term profitability criteria, rather than more global and strategic objectives relating directly to survival of the firm. Jelinek and Goldhar [29], in talking about the limitations of DCF procedures today, draw a comparison between the economies of scale of yesterday's factories versus the economies of scope of the factory of the future. According to them, yesterday's factories worked on the principle of, "the bigger, the better."

In contrast, today's factories have variability and responsiveness, not rigidity and standardization, at their heart. And, it is strategic advantages such as these, that, according to the authors, are intangible and unaccountable in the traditional forms of analysis. Meredith and Suresh [35] also feel the same way, saying that "many worthwhile projects have been turned down because the qualitative benefits could not be included in the justification procedure, while the direct cost savings were insufficient to meet the financial hurdles set by the firm". They argue for a multidimensional perspective instead of a unidirectional financial one. Kaplan [30] and Rosenthal [39] are also of the same opinion.

Canada and Sullivan [8] say that today's manufacturing systems have benefits that are almost impossible to quantify and as such do not fall within the sphere of today's cost accounting systems. Thus these "intangibles" are assumed to have an implicit value of zero if traditional methods are used, which has the effect of completely ignoring these benefits.

2.5 Multi-Attribute Evaluation of Capital Investments

An answer to the insufficiency of traditional financial evaluation techniques may lie in the multiattribute analysis and evaluation of projects. Canada and Sullivan [8] call multiattribute evaluation of projects a "conscious and viable" technique that is beneficial in several ways, such as: 1) forcing focus on objectives, alternatives, attributes, and risks; 2) facilitating communications between analysts; 3) promoting more reasoned estimating procedures; and 4) "selling" recommendations by communicating what at least appears to be good rationale. They also caution against the limitations of the technique, such as: 1) requiring explicit preferences between various outcomes and attributes, which may not be easily statable; 2) lulling one toward ignoring any alternatives or intangibles which are not formally considered in the particular methodology used; 3) failing to consider the effect of risk and uncertainty; and 4) assuming independence, rather than considering interactive effects among attributes.

The problem of multi-attribute analysis and decision making requires a large number of individual decisions and extensive examination of preferences by the decision maker. As the size of the problem increases, so do the number of decisions. Classical decision rules such as dominance, maximin, and maximax can be used when no preference information is given by the decision maker. This was also mentioned by Hwang and Masud [27] in their survey of multiple attribute decision making. Such information may be given by the decision maker in various ways such as standard level of each attribute, relative importance of each attribute by either ordinal or cardinal preference, and marginal rate of substitution between attributes. These are discussed briefly by Hwang and Masud [27]. Cardinal preference methods, such as the linear assignment method, simple additive weighting method, and hierarchical additive weighting method, are possibly the most common ways of expressing the interattribute preference information. Bernardo and Blin [3] for the linear assignment method, McCrimmon [34], and Churchman and Ackoff [11] for the simple additive weighting method, and Saaty [40] for the heirarchical weighting method, are particularly succinct references.

Once these values are attached to the attributes, they interact with attributes from the environment to provide the basis of calculation of the outcome or aspiration level of each alternative. The problem in real life is more fluid than that. An accurate prediction of attributes is extremely unlikely, in purely quantitative terms. The decision maker has preferences that may well be described in qualitative terms but may be extremely difficult to quantify. Under these circumstances, the decision maker usually abstracts the problem and constructs a simple model. This then leads to discrepancies between the calculated outcome and the outcome of the real problem. Bonissone [4] says that this problem may be overcome by using the fuzzy set approach.

2.6 Uncertainty Modelling Via Fuzzy Set Theory

Monte Carlo simulation models, closed-form analysis models, or sensitivity analysis can in varying degrees model evaluation and decision-making under risk and uncertainty. However, there is a qualitatively different kind of uncertainty which is not covered by these methods -- that is, inexactness, ill-definedness, vagueness, or, in short, fuzziness. Many situations occur where probability, the underlying notion to the first two methods cited above, is not sufficient to describe reality. Situations where doubt arises about the exactness of concepts, correctness of statements and judgments, degree of credibility, and so on have little to do with probability of occurrence. The fuzzy set theory, on the other hand, is meant precisely to model these situations.

This theory was first introduced by Prof. L. A. Zadeh [52] in 1965. The theory has been modified, extended, and in general worked upon by an increasing number of professionals, and today it stands as one of the most promising research areas. The central concept of Zadeh's theory is the membership function which represents numerically the degree to which an element belongs to a set. This function takes on values between zero and 1, and is an extension of the idea of a characteristic function for a set. The membership function is assessed subjectively in any instance; small values represent a low degree of membership and high values represent a high degree of membership.

Kaufman and Gupta [31] consider a fuzzy set to be an extension of the principle of the interval of confidence. This extension is simply based on the idea that instead of considering the interval of confidence at one unique level, it is considered at several levels and more generally at all levels from zero to one. The "maximum of presumption" is at level one and the minimum at level zero. Thus defining it in a rigorous manner [13][32][52], let X be a classical set of objects, called the universe, whose generic elements are denoted x. Membership in a classical subset of A of X is often viewed as a characteristic function μ_A from X to $\{0,1\}$ such that:

$$\mu_A(x) = \begin{cases} 1 & \text{iff } x \in A \\ 0 & \text{iff } x \notin A \end{cases} .$$

The set {0,1} is called a valuation set. If the valuation set is allowed to be the real interval [0,1], A is called a fuzzy set. $\mu_A(x)$ is the grade of membership of x in A. The closer the value of $\mu_A(x)$ is to 1, the more x belongs to A. Clearly, A is a subset of X that has no sharp boundary. The approach above thus provides a tool for modeling human-centered systems, according to Zadeh. He says fuzziness pervades most human perception and thinking processes. One of the most important facets of human thinking is the ability to summarize information into " labels of fuzzy sets which bear an approximate relation to the primary data."

Fuzzy set theory is often confused as an alternative to probability theory, as discussed above. However this point is at the root of many misunderstandings as to the meaning, significance, and purpose of this theory. According to Zadeh [52][53][54], fuzzy set theory can be looked upon as a theory of possibility, rather than probability. According to him, possibility is related to the perception of the degree of feasibility or the ease of attainment, whereas probability is associated with a degree of likelihood, belief, frequency, or proportion. He introduced the concept of a possibility distribution, which was later extended and generalized by Dubois and Prade [13] and others [31][51]. Let A be a nonfuzzy set of X, and v a variable on X. To say that v takes its value in A indicates that any element in A could possibly be a value of v, and that any element not in A cannot be a value of v. The statement "v takes its value in A" can be viewed as inducing a possibility distribution π over X associating with each element x the possibility that x is a value of v:

$$\Pi(v = x) = \pi(x) = \begin{cases} 1 & \text{if } x \in A \\ 0 & \text{otherwise} \end{cases}$$

Next, assume A is a fuzzy set that acts as a fuzzy restriction on the possible value of v. Then an extension of the above interpretation is that A induces a possibility distribution that is equal to μ_a on the values of v:

$$\Pi(v = x) = \pi(x) = \mu_a(x)$$

Since the expression of a possibility distribution can be viewed as a fuzzy set, possibility distributions may be manipulated by the combination rules of fuzzy sets and, more particularly of fuzzy restrictions. The following paragraphs will discuss the literature that has been published on the application of fuzzy set theory to the economic evaluation of capital investment and to multi-attribute decision making.

Buckley [7] discusses the use of fuzzy numbers to model cash flows and calculate the NPV and IRR as fuzzy values and then rank the alternatives accordingly. According to Buckley [7], given a net fuzzy cash flow $\mathcal{P} = P_0, P_1, ..., P_n$, with r a fuzzy interest rate representing the cost of capital for the firm, the fuzzy net NPV is given by:

$$NPV(\mathcal{P}, n) = P_0 \oplus \sum_{i=1}^{n} PV_{k(i)}(P_i, i)$$

where $\oplus$ is the fuzzy equivalent of the algebraic operator, "+," $\sum$ is fuzzy addition, k(i) = 1 when P_i is negative, and k(i) = 2 for positive P_i. The membership function $\mu(x \mid \mathcal{P}, n)$ is defined by

$$\mu(x \mid \mathcal{P}, n) = (\alpha_{n1}, f_{n1}(y \mid \mathcal{P})/\alpha_{n2}, \alpha_{n3}/f_{n2}(y \mid \mathcal{P}), \alpha_{n4})$$

where:

$$f_{ni}(y \mid \mathcal{P}) = \sum_{j=0}^{n} f_{ni}(y \mid P_j)[1 + f_{k(j)}(y \mid r_0)]^{-j}$$

for i = 1, 2, where k(j) = i for negative P_j, and k(j) = 3 - i for positive P_j. The projects with a

NPV less than zero will of course be rejected and the others ranked according to their NPV value. (Zero here is understood as some appropriate representation of fuzzy zero depending upon the relative values of the cash flows). Ward [48] uses the concept of the flat or trapezoidal fuzzy numbers, introduced by Dubois and Prade [13]. Like most other researchers, he requires that the numbers have membership functions that are normal and convex. A fuzzy set A is normal if:

$$\mathrm{hgt}(\mu_A(x)) = 1$$

where hgt(.), or height, is the supremum of $\mu_A(x)$ over X. This condition ensures that at least one real number is totally in the set. Fuzzy number A is convex if:

$$\mu_A(kx_1 + (1-k)x_2) > \min(\mu_A(x_1), \mu_A(x_2))$$

for all x_1 and x_2 in X and for all k in [0,1]; this condition ensures that the membership function will be piecewise continuous. Further it ensures that at the point (or interval) where the membership function is 1.0, the function on the left will be nondecreasing and that it will be nonincreasing on the right. Thus the membership function exhibits peakedness in the vicinity of its highest point. Ward's [48] treatment of the problem is conceptually the same as Buckley's except for the fact that Ward assumes that either the time or amount can be fuzzy but not both.

Yager [51], in 1980, extended the usefulness of fuzzy sets to decision making using the linguistic approach. He recognized the fact that most communication between an analyst and the decision maker takes place in the linguistic media and, therefore, the linguistic approach has the advantage of not unduly restricting the decision maker in expressing information, and "allowing him free play of his intuition." The analyst would then try using the linguistic structure available in fuzzy sets to model the relationships expressed linguistically by the decision maker. The problem arises here when the analysis needs to take into account some attributes that do have numerical values attached to them.

Laarhoven and Pedrycz [32] presented a method for choosing from among a number of alternatives under conflicting criteria. Their method consisted of a matrix displaying ratios expressing the relative significance of each pair of factors from which weights can be known. The ratios are fuzzy and hence are taken to be representative of the decision-maker's opinion with regard to the importance of the pair of factors. Their method was employed at two different levels: first, to find the fuzzy weights for the decision criteria and second, to find weights for the alternatives under each of the decision criteria. The results of their method were in the form of fuzzy scores for each alternative. The sensitivities were also calculated.

In his survey of decision-analysis-oriented methods based on the concept of a fuzzy number, Dubois [12] found that fuzzy numbers can be used to perform a sensitivity analysis on scoring models where probability values and weights of attributes cannot be precisely estimated, but are obtained through verbal statements. Algorithms for computing fuzzy global ratings were provided.

Jain [28] developed the weighted-rating method for decision making in fuzzy situations by defining the ill-defined quantity as a fuzzy set. This system is good when the alternatives are known in terms of linguistic or qualitative variables like "good," "fair," "maybe," etc. His approach selects the method which has the best compromise in the value of the utility and its grade of membership which, he says, is analogous to the method employed by the human thought process. It not only presents the optimal alternative but also gives information about the relative merits of the other available alternatives. This is useful when, due to any reason, a suboptimal alternative may also have to be considered.

Buckley [6], however, says that all these methods suffer from at least one of the following drawbacks: 1) The procedure is computationally complex and, hence, difficult to implement with the usual set of judges and analysts; 2) it is unintuitive, which also hinders implementation etc.; 3) assumes one criterion or one expert; 4) presupposes the existence of some fuzzy function or relation across the alternatives; and 5) produces a crisp ranking of the issues from the fuzzy data. He presents a method which, he says, is intuitive, computationally simple and easily implemented. His method can employ multiple experts who use fuzzy numbers to express their preferences and then fuzzy arithmetic is employed to compute an issue's fuzzy ranking. This then leads to a partition of the alternatives into sets H_1,H_2,.... where H_1 contains the highest ranked alternatives, H_2 has the second highest ranked alternatives etc.

2.7 Computer Applications for Economic Evaluation

The use of computers is quite obviously essential, since a decision support system, especially one as complex as the one that was developed in this research, would be extremely difficult to work with otherwise. In the past, mainframes rather than micros have been used, but this could be because of constraints of speed and memory. Today's microcomputers have become significantly faster with much bigger memories. They are also a lot cheaper and consequently more accessible to people. A brief review of the number and diversity of available packages in this area of investment analysis will serve to prove the popularity of the microcomputer.

This review is based mostly on an extensive summary listing of the software packages available today to carry out an economic evaluation of a project on a microcomputer that was compiled by Canada and Hodge [9]. The first on the list is software developed by Century Software Systems called Business Management I: Financial Decisions. It is a series of modules which performs before-tax and after-tax analysis, internal rate of return calculations, and net present worth calculations. The Cash Flow Analyser, by G. A. Fleischer and Assoc., performs NPV and IRR calculations as well as providing for sensitivity analysis and graphical representations of the NPV versus the interest rate. The software package, Economic Analysis by IIE Microsoftware, performs after-tax cash flow analysis, as well as IRR calculations. It also performs decision tree analysis with up to 100 decision nodes possible. Predict!, a package developed by Unison Tech., Inc., works like a spreadsheet program but is capable of handling risk and uncertainty by means of probability distributions. Payback+, by MiCAPP, Inc., requires no programming and performs the calculations for NPV and payback. The Venture Analyst, developed by a company of the same name, also requires no programming, and, in addition to cash flow analysis, financial ratios, IRR, NPV, and breakeven analysis, it also performs a sensitivity analysis. It also has the capability of performing a Monte Carlo simulation. As this review indicates, there are no capital investment evaluation packages available, as yet, that combine economic evaluation, multiattribute analysis, and uncertainty modelling by using fuzzy logic.

2.8 Summary and Conclusions

There has already been considerable research in the area of capital investment decision making in uncertain, imprecise environments. The models developed, most of them based on probability theory, handle the element of uncertainty well enough, but the element of imprecision is still a loose end. The computer, of course, is something of a necessity, given it's superiority over the human brain when it comes to number crunching and programmed reasoning. Therefore, an improved solution to the problem would be a decision support system capable of using the best of both worlds: the computer and the human brain. Fuzzy set theory seems to be an ideal platform on which to develop a model closely approximating human reasoning and to use it in conjunction with the microcomputer to achieve this aim.

Research on capital investment analysis has been extensive and innumerable models have been developed. Some have been based on traditional economic methodologies, while some have attempted to incorporate multiattribute analysis as well. Then again, some have incorporated uncertainty and risk handling, while others have not. The fuzzy set theory of Zadeh has been used in the development of some economic models, but on a very simplistic level, and that too, to a very limited extent. This research is unique from the point of view of developing an integrated model incorporating economic evaluation, as well as the evaluation of non-economic, including intangible attributes, and using fuzzy logic to model the prevalent uncertainty and imprecision in today's industrial arena and in human reasoning. It is hoped that this research will provide one way to improve capital investment decisions.

3. Methodology

3.1 Introduction

The capital investment decision-making problem, discussed in the previous section, has been the subject of considerable research in the past few years. Methodologies developed have grown consistently more complex and sophisticated. The existing evaluation and decision-making procedures do have their advantages -- a structured and organized approach, for example --but they still appear to be a distance away from bridging that gap between logical thinking and the human thought process. They have a severe constraint in that they require working in purely numerical or financial terms. The methodology presented here, based in part on the literature presented in Chapter 2, attempts to overcome this constraint while at the same time retaining an organized approach to the problem. It attempts to bridge the gap between machine thinking and human thinking by working in numerical as well as linguistic terms.

3.2 The Solution Technique

This section gives a broad overview of the structure of the model that has been developed during the course of this research. The attributes that need to be considered in the justification procedure may be divided into two main categories -- economic and non-economic. The economic attributes are those that can be expressed numerically in terms of cash flows and interest rates. The non-economic attributes are the other attributes that cannot be converted into monetary terms but are nevertheless important in the justification procedure. As has been discussed, it is essential that all the relevant attributes from both these categories be considered if a fair evaluation is to be made. The economic attributes are all essentially to be considered simultaneously, using formulae from engineering economy.

However, the non-economic attributes are not all the same. They may be divided into two main categories -- short-term benefits and long-term benefits. Therefore, in order to provide for maximum flexibility in terms of evaluating the project consistent with the goals of the firm, it is essential that the analysis must progress along these three distinct fronts. Consequently, the model is divided into three main modules. The first one, called the economic justification module handles the first main category of attributes. The other two modules, namely, the operational justification module and the strategic justification module, handle the non-economic categories of attributes. The operational justification module is aimed at the short-term benefits from the project, while the strategic justification module is aimed at the ~~short~~ LONG-term benefits that may be derived from the project.

Each of the three modules function as independent decision-support modules. The economic module returns fuzzy net present worths and payback periods. The other two modules have multiple attributes which are considered simultaneously. The analyst has freedom to choose the attributes to be considered in each module. The operational module returns a fuzzy number and a linguistic interpretation to it, both of which represent the operational desirability of the project. The strategic module returns a single linguistic value which represents the desirability of the particular project from a strategic standpoint. Additionally, the operational and strategic modules individually return the results of sensitivity analyses. Thus the model returns five main values and associated sensitivity data, on the basis of which the analyst may make decisions. A graphical interpretation of the structure of the model is shown in Figure 1.

3.3 Type of Fuzzy Subsets Used in This Model

All representations in this model are continuous fuzzy subsets and have the form of the L-R fuzzy number as defined by Dubois and Prade [13]. The convention for writing these numbers will be the same as used by Buckley [6][7]. A fuzzy number is defined as a special, normal and convex fuzzy subset of the real number universe. Thus, a fuzzy number M^* will have the membership function $\mu(x \mid M^*)$ that may be defined generically as:

$$\mu(x \mid M^*) = (m_1, f_1(y \mid M^*)/m_2, m_3/f_2(y \mid M^*), m_4)$$

where $m_1 < m_2 \leq m_3 < m_4$, $f_1(y \mid M^*)$ is a continuous monotone increasing function of y for $0 \leq y \leq 1$ with $f_1(0 \mid M^*) = m_1$ and $f_1(1 \mid M^*) = m_2$, and $f_2(y \mid M^*)$ is a continuous monotone decreasing function of y for $0 \leq y \leq 1$ with $f_2(0 \mid M^*) = m_4$ and $f_2(y \mid M^*) = m_3$. The numbers used in this module will employ straight line segments for $\mu(x \mid M^*)$ on $[m_1, m_2]$ and $[m_3, m_4]$, so that:

$$x = f_1(y \mid M^*) = (m_2 - m_1)y + m_1$$
$$x = f_2(y \mid M^*) = (m_3 - m_4)y + m_4$$

These trapezoidal shaped fuzzy numbers may be written as (m_1, m_2, m_3, m_4). Figure 2 shows a the graph for the membership function of such a trapezoidal number. These trapezoidal numbers are very flexible in that they can represent crisp numbers and interval numbers as well. Crisp numbers are real numbers written as fuzzy numbers, whereas interval numbers are fuzzy numbers representing an interval having a possibility level of 1 for every value in it. Thus, the number 3

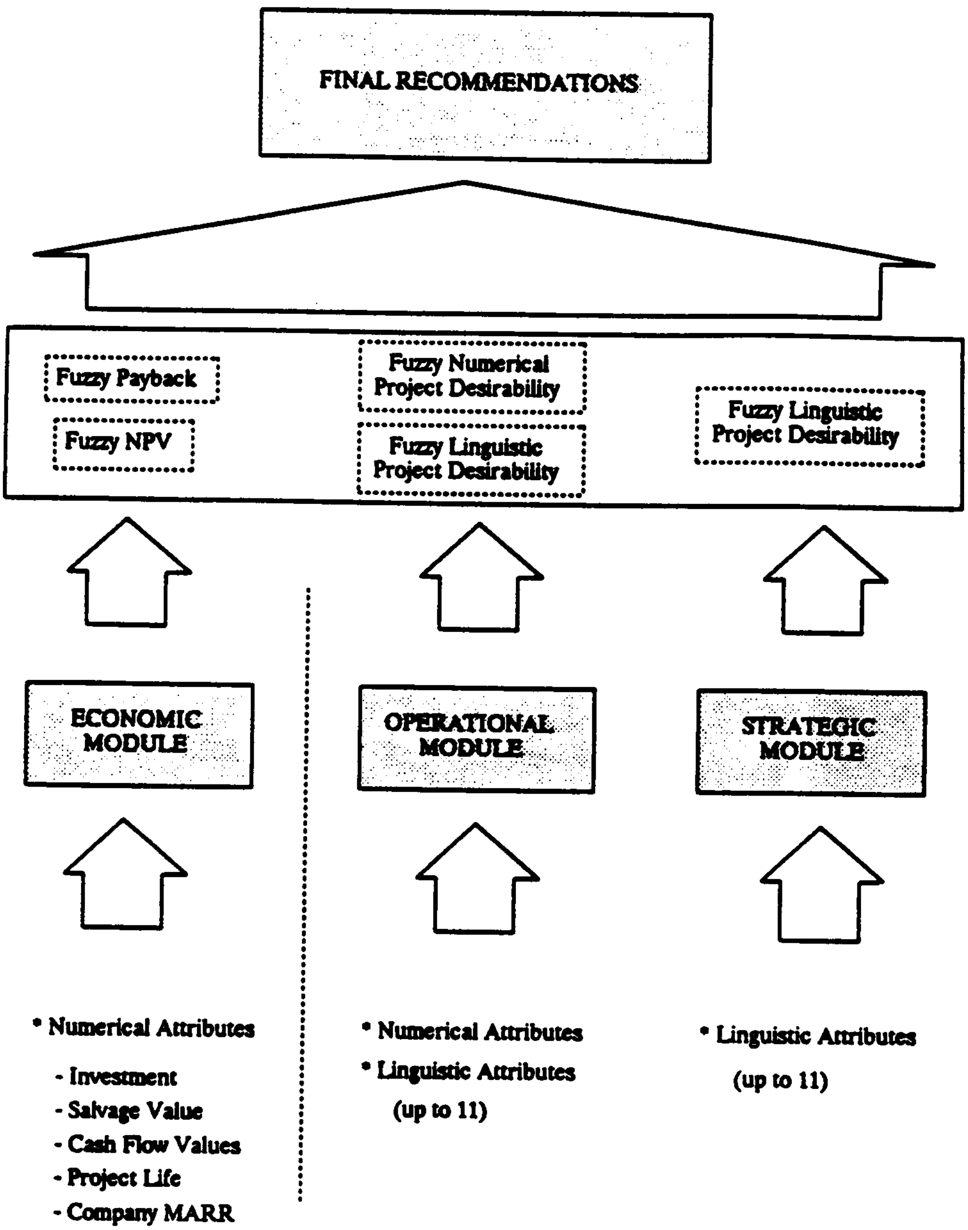

Figure 1: Overall Structure of the Model

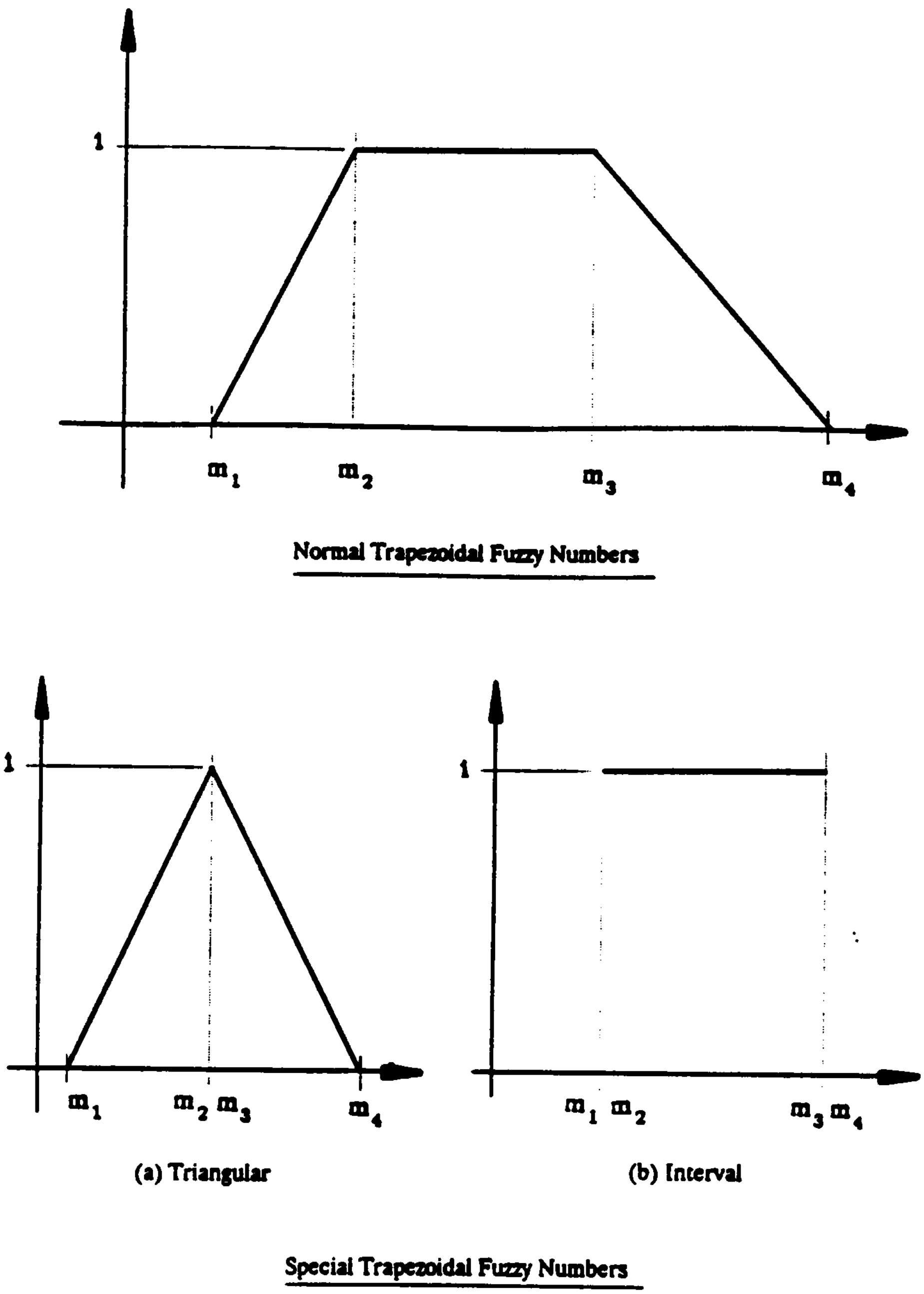

Figure 2: Trapezoidal Fuzzy Numbers

would simply be represented as the crisp number (3, 3, 3, 3) and the interval from 5 to 8 would be represented as the interval number (5, 5, 8, 8). This permits "mixed arithmetics," i.e. it allows the use of crisp numbers and interval numbers in combination with fuzzy numbers, in cases where more precise information is available. Consequently, it allows increased modelling flexibility.

3.4 The Economic Module

The economic module interactively gathers data from the analyst, performs the calculations, and returns two measures of merit -- the payback period and the net present value (NPV). The calculation of the payback period is simply a matter of fuzzy subtraction. The calculation of the fuzzy net present worth is a more complex mathematical process and is based in part on the theoretical model developed by Buckley [7].

3.4.1 Buckley's Financial Model for Calculating the NPV

Buckley [7] developed a theoretical model for the mathematics of finance in which he discusses the calculation of the net fuzzy future worth and the net fuzzy present worth of a set of cash flows that are modelled as fuzzy numbers. The set of cash flows can be defined as single fuzzy cash flows or as regular fuzzy annuities. The model extends to incorporate fuzzy time periods as well. The salient features of this model for calculating the fuzzy net present worth are presented below.

The fuzzy single cash flow is represented by the symbol S^*, the fuzzy regular annuity by A^*, the fuzzy interest rate per compounding period by r^*, and the fuzzy number of periods n_i^*. Buckley's model for the net present value is first discussed with the time period expressed as a non-fuzzy number n, and then the discussion is extended to include fuzzy time periods as well. Buckley uses discrete fuzzy subsets to model the time of occurrence of the cash flows. The model developed in this research makes use of continuous numbers instead. However, the underlying theory is similar, and his discussion on the discrete fuzzy analysis of the time of occurrence has been included.

3.4.1 (a) FUZZY NPV OF A SINGULAR CASH FLOW: In non-fuzzy mathematics, the present value PV(S) of an amount S, n periods in the future, for an interest rate of r is given by:

$$PV(S) = S(1 + r)^{-n}$$

In fuzzy mathematics, for the present value $PV(S^*, n)$ of a fuzzy amount S^*, n periods in the future, for a given interest rate of r^*, two definitions will be required, one for a positive S^*, and the other for a negative S^*.

Definition 1 - $PV_1(S^*, n) = P^*$ if and only if P^* is a fuzzy number and $P^* \odot (1 \oplus r^*)^n = S^*$.
Definition 2 - $PV_2(S^*, n) = P^*$ if and only if P^* is a fuzzy number and $P^* = S^* \odot (1 \oplus r^*)^{-n}$.
(The "$\odot$" operator is the fuzzy equivalent of the algebraic multiplication operator and the "$\oplus$" is the fuzzy equivalent of the algebraic addition operator.)

The necessity of these two definitions will become clear as the discussion progresses. To understand why it is essential that P^* be a fuzzy number, the membership functions for $PV_1(S^*, n)$ and $PV_2(S^*, n)$, given by $\mu_1(x | S^*, n)$ and $\mu_2(x | S^*, n)$ respectively, must be defined. The membership function $\mu_1(x | S^*, n)$ is determined by:

$$f_i(y | P^*) = f_i(y | S^*)(1 + f_i(y | r^*))^{-n}$$

for $i = 1,2$ and $p_1 = f_1(0|P^*)$, $p_2 = f_1(1|P^*)$, $p_3 = f_2(1|P^*)$, $p_4 = f_2(0|P^*)$. Then P^* will be a fuzzy number if and only if $f_1(y|P^*)$ is increasing, $f_2(y|P^*)$ is decreasing, and $p_2 \leq p_3$. If any of these conditions fail, then $PV_1(S^*, n)$ is not defined. The membership function $\mu_2(x|S^*, n)$ is determined by:

$$f_i(y|P^*) = f_i(y|S^*)(1 + f_{3-i}(y|r^*))^{-n}$$

for $i = 1,2$ and $p_1 = f_1(0|P^*)$, $p_2 = f_1(1|P^*)$, $p_3 = f_2(1|P^*)$, and $p_4 = f_2(0|P^*)$. For $PV_2(S^*, n)$ to be defined it must be that $f(y|P^*)$ is increasing, $f_2(y|P^*)$ is decreasing and $p_2 \leq p_3$.

If S^* is negative, then $PV_1(S^*, n)$ exists. Otherwise it may not exist. On the other hand, if S^* is positive, then $PV_2(S^*, n)$ exists. Otherwise it may not. It is for this reason that the two definitions stated above were needed. This can be proven mathematically as well as by numerical examples. For the proof, and a numerical example, the reader is referred to Appendix A.

Buckley then extends the model to the case where the number of periods is also fuzzy, n^*. If the number of periods is also modelled as a fuzzy subset, then the membership functions $\mu_1(x|S^*)$ and $\mu_2(x|S^*)$ are given by the following equations:

$$\mu_1(x|S^*) = \max_{1 \leq i \leq K}(\min(\mu_1(x|S^*, n_i), \lambda_i))$$

and:

$$\mu_2(x|S^*) = \max(\min(\mu_2(x|S^*, n_i), \lambda_i))$$

These two equations say that in order to find $\mu(S^*)$, first determine $\mu(S^*, n_i)$, cut off at height λ_i, and then take the maximum of these fuzzy sets. Due to this set of operations, the fuzzy subsets may not remain convex and/or normal. It is therefore entirely possible that when the time periods are fuzzy, $PV_1(S^*)$ and $PV_2(S^*)$ may not be fuzzy numbers, even though they will be fuzzy subsets.

3.4.1 (b) FUZZY NPV OF A REGULAR ANNUITY: In the consideration of annuities in non-fuzzy mathematics, the present worth P_n, for periodic payments A made at the end of each interest period for n periods, and for a given interest rate of r, is given by:

$$P_n = A\gamma(n, r)$$

where the actuarial function γ is:

$$\gamma(n, r) = (1 - (1 + r)^{-n})/r.$$

In non-fuzzy mathematics, the present value P_n^* of A^* payments made at the end of each period for n periods and for an interest rate of r^* is given by:

$$P^* = \sum_{i=1}^{n} PV_2(A^*, n)$$

where Σ represents fuzzy summation, and A^* is assumed positive. (The case for a negative A^* is similar except that it is modelled on PV_1 rather than PV_2). In the equation given above, if A^* is factored out, then the membership function $\mu(x \mid P_n^*)$ for P_n^* is determined by:

$$f_{ni}(y \mid P_n^*) = f_i(y \mid A^*)\gamma(n, f_{3-i}(y \mid r^*))$$

for $i = 1, 2$ and $p_{n1} = f_{n1}(0 \mid P_n)$........$p_{n4} = f_{n2}(1 \mid P_n^*)$. Here P_n^* is a fuzzy number.

If the number of periods is fuzzy, n^*, then the membership function, $\mu(x \mid P^*)$, for the present worth, P^*, is given by:

$$\mu(x \mid P^*) = \max_{1 \le i \le K} (\min (\mu(x \mid P_{ni}), \lambda_i)).$$

3.4.2 Variations from Buckley's Financial Model

Buckley's model requires very complex mathematics in the development of the computer program. To simplify the development of the computer model, while at the same maintaining the basic essence of Buckley's model, some changes to his model were incorporated. Instead of discrete fuzzy numbers, continuous fuzzy numbers of the type used to model the cash flows, etc. were employed. This permitted the use of some approximate fuzzy equivalents of simple algebraic functions like multiplication and division. These approximations have been used before and do not introduce any significant errors [4]. On the other hand, all the numbers used in the calculation, as well as the results, remain trapezoidal, leading to a simplified algorithm for calculating the NPV.

3.5 The Operational and Strategic Modules

As mentioned earlier, today's advanced manufacturing systems have more than just economic benefits, and consequently it is essential that the project evaluation take these benefits into consideration. The operational and strategic modules are designed to evaluate these non-economic benefits. The first kind, namely the short-term benefits, are handled by the operational module. Examples of such benefits are improved quality, flexibility in terms of production scheduling, reduced inventory, reduced setup times, and less maintenance. These are benefits that the firm would obtain within two to three years of the implementation of the project. Typically they are the benefits that relatively smaller firms with low liquidity positions would look at more strongly. The second kind, namely the long-term benefits, are handled by the strategic module. These benefits are the ones that contribute toward the overall business objectives of the firm. These benefits may be increased competitiveness in the market, enhanced corporate image, overall technological advancement, and flexibility in terms of new products. These benefits may be reason enough for a firm to undertake the project, even though the short-term benefits do not indicate a high degree of desirability.

The operational module has the capability to handle numerical as well as linguistic attributes. The analyst may chose to provide a numerical value for the rating and weight of a specific attribute, or he may chose to define the quality and importance of an attribute by any of the given linguistic attributes. The numerical ratings and weights for the attributes are then converted into fuzzy numbers. The linguistic terms provided are the following: 1) very high (very important), 2) high (important), 3) more or less high (more or less important), 4) more or less low (more or less unimportant), 5) low (unimportant), and 6) very low (least important). The analyst assigns any of these terms to the rating and weight of the linguistic attribute, and these are then converted into a fuzzy number by a predetermined scale. To enable modelling simplicity, the analyst is limited to assigning both the rating and weight for a specific attribute either numerically or linguistically. A combination of both is not permitted.

The fuzzy numbers from the numerical and the linguistic attributes are then normalized to the same scale and the desirability factor for the project is calculated. The procedure for calculating the desirability is based on a theoretical model developed by Buckley [6], which is described in the following section. The operational module returns two values for the project desirability -- a fuzzy number and its linguistic interpretation. This is followed by a sensitivity analysis that provides information on how the desirability of the project would change with changing values for the ratings and weights for all the attributes taken individually.

The strategic module has a structure similar to the operational module, except that it only considers linguistic attributes. For every attribute to be considered, the analyst is prompted for a linguistic value for the rating and weight of the attribute, from the same set of choices as the ones in the operational module. The justification for the strategic module's handling only linguistic attributes is that since this module is considering long-term goals, the uncertainty prevalent and consequently the fuzziness, would be so high that it would be very difficult to specify actual numbers if at all. The calculation of the strategic desirability of the project is also based on Buckley's model [6]. The output of the strategic module is also linguistic. That is, the strategic module returns a linguistic answer, such as "very high" or "more or less low" to the question of the desirability of the project strategically. Here too, a sensitivity analysis, on the same lines as the one in the operational module is performed.

3.5.1 Buckley's Fuzzy Multi-Attribute Decision Model

Buckley [6] has developed a theoretical model for a fuzzy multi-attribute analysis. Buckley's model is generalized to multiple judges and includes a procedure for comparing and ranking alternatives. However, here it is presented with the restriction of a single judge. Also, as will be discussed in the next section, other minor deviations from his model have been incorporated in the computer model developed. These were necessitated partly due to considerations of simplicity and partly due to the fact that the current computer model doesn't rank the alternatives.

On the basis of the inputs provided by the analyst, the attributes to be considered are defined in terms of fuzzy numbers. Let the fuzzy number:

$$a^*_{ik} = (\alpha_{ik}, \beta_{ik}, \gamma_{ik}, \delta_{ik})$$

generically define the rating for the alternative A_i with respect to the attribute C_k. If $\mathcal{L}$ is the set of fuzzy numbers and $\mathcal{L}_0$ the set of positive fuzzy numbers, then $a_{ik} \epsilon \mathcal{L}_0$. Let the weights attached to each attribute be given by:

$$b_k = (\xi_k, \zeta_k, \eta_k, \theta_k)$$

In other words, b_k represents the importance of attribute C_k with respect to the particular alternative. (Here the fuzzy numbers $(\alpha, \beta, \gamma, \delta)$ and $(\xi, \zeta, \eta, \theta)$ correspond respectively to (m_1, m_2, m_3, m_4) in Figure 2. Also, $\alpha, \beta, \gamma, \delta, \xi, \zeta, \eta, \theta \epsilon \{0, 1, 2, \ldots\ldots\ldots L\}$). Let w_i represent the overall weight or desirability factor for the alternative A_i. The fuzzy number w_i may be described as $(W_i[L_1, L_2]/X_i, Y_i/Z_i[U_1, U_2])$ where W_i, X_i, Y_i, Z_i, L_1, L_2, U_1, and U_2 are defined as follows:

$$W_i = \sum_{k=1}^{K} \alpha_{ik}\xi_k/KL$$

$$X_i = \sum_{k=1}^{K} \beta_{ik}\zeta_k/KL$$

$$Y_i = \sum_{k=1}^{K} \gamma_{ik}\eta_k/KL$$

$$Z_i = \sum_{k=1}^{K} \delta_{ik}\theta_k/KL$$

$$L_1 = \sum_{k=1}^{K} (\beta_{ik} - \alpha_{ik})(\zeta_k - \xi_k)/KL,$$

$$L_2 = \sum_{k=1}^{K} [\alpha_{ik}(\zeta_k - \xi_k) + \xi_k(\beta_{ik} - \alpha_{ik})]/KL,$$

$$U_1 = \sum_{k=1}^{K} (\delta_{ik} - \gamma_{ik})(\theta_k - \eta_k)/KL$$

$$U_2 = \sum_{k=1}^{K} [\theta_k(\delta_{ik} - \gamma_{ik}) + \delta_{ik}(\theta_k - \eta_k)]/KL$$

Division by KL ensures that all the fuzzy weights have their support in [0, L], and the overall weight is averaged over all the attributes. The graph of the membership function of the overall weight, w_i, for the alternative is shown in Figure 3 and can be defined as:

a) zero to the left of W_i

b) $L_1 y^2 + L_2 y + W_i = x$ on $[W_i, X_i]$

c) a horizontal line from $(X_i, 1)$ to $(Y_i, 1)$

d) $U_1 y^2 + U_2 y + Z_i = x$ on $[Y_i, Z_i]$, and

e) zero to the right of Z_i.

Thus, according to Buckley's model, the final result is no longer a trapezoidal number. As is discussed in the next section, at this point there is a variation in the model developed in this research, compared to Buckley's model.

3.5.2 Variations from Buckley's Model

The operational and strategic modules of the model developed as a part of this research have their basis in Buckley's model for fuzzy multi-attribute analysis. However, as mentioned in the previous section, some modifications have been made. Firstly, in the computer model, the values of L_1, L_2, U_1, and U_2 have been taken as zero. The effect of this is to reduce the quadratic describing the slope of the fuzzy subset, shown as a curve in Figure 3, to a linear equation. The consequence is that the entire analysis then involves only trapezoidal numbers, facilitating the use of the fuzzy approximations of simple algebraic functions. This reduces the computational burden while retaining most of the precision and information content [4].

Secondly, since Buckley's model includes ranking of alternatives as the end result, he has not calculated the weighted sums of each of the alternatives by normalizing the specified weights. In the model developed herein, since ranking was not an objective, it was necessary to calculate project desirabilities by normalizing the weights. This was accomplished in much the same way as would be done using single crisp numbers, except that fuzzy approximations were used for multiplication and division.

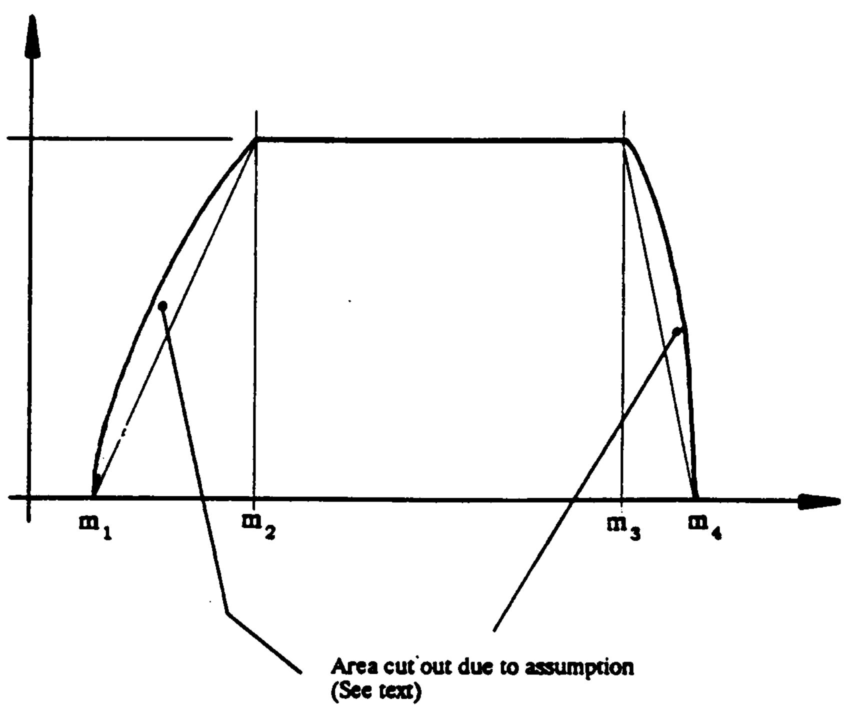

Figure 3: Graph of Fuzzy Number Resulting from Buckley's Model

3.6 Summary

Unlike probability theory based models, the model developed can account for not only the uncertainty, but the imprecision associated with the decision-making environment as well. As will be seen in the next chapter, this model provides a way to make the decision-making process more like the human thought process, since the fuzzy set theory is more capable of handling linguistic data such as "approximately 5" or "reasonably low." It also enables the analyst to look at the project from a much larger perspective, since it takes into account, not just the traditional economic benefits, but the operational benefits, some of which may be intangible, and more importantly, the intangible strategic benefits as well. It does so by combining parts of two separate theoretical models developed by Buckley -- one for fuzzy economic evaluation [7] and the second for fuzzy multi-attribute decision making [6] -- and then developing a computer model from the combination. The analysis of the operational and strategic attributes facilitates the development of a way to classify distinctly the operational and strategic benefits which may be of importance in capital investments, particularly computer integrated manufacturing and other new technologies.

4. The Computer Model

4.1 Introduction

This chapter discusses in detail the computer model developed. Flowcharts depicting the overall model as well as the individual modules are presented. The algorithms used to determine fuzzy numbers for a given variable are also described. The linguistic quantifiers used in the operational and strategic modules are discussed, with reference to their internal representation as fuzzy numbers, and the reconversion of fuzzy numbers into linguistic quantifiers. Some of the software and hardware considerations that went into the development of the model are also discussed. The code for the computer model is contained in Appendix B. Additionally, Appendix C contains a brief guide to implementing the computer model.

The computer model activates the three modules sequentially. The sequence of activation is 1) economic, 2) operational, 3) strategic. The results of each of the modules are written into separate files. The files can be either viewed on the terminal or printed if a printer is handy. After every module, the user has the option of either running that module again or progressing to the next module. In order to keep the model structure simple, the analyst is not permitted to return to a previous module. Additionally, all three modules must be run. This is to "force" the analyst to consider all the three aspects of the project in question, keeping in mind that enabling more informed decisions is one of the major contributions of the research. The reader is reminded of Figure 1 which showed the overall structure of the model including input and output. A flowchart depicting the computer model structure is shown in Figure 4. Subsequent sections discuss the working of the three modules individually.

4.2 The Modelling of Fuzzy Numbers

This section discusses the procedure for the determination of the fuzzy numbers to represent the various parameters, such as cash flows, interest rate, attribute ratings and attribute weights that are used in the model. The algorithm is presented below:

1. The system prompts the analyst to enter a base value for the parameter.
2. Then, the system asks the analyst if there is any possibility of variation in the base value entered. If the answer is "no," then that signifies that there is no imprecision involved. However, if the answer to the question is "yes," then the system prompts the analyst to enter the maximum percentage variation that is envisaged, on either side of the original value entered. The analyst is limited to a maximum percentage variation of ±50%, to simplify the calculations. These two variation points entered will be points m_2 and m_3 of the fuzzy number respectively. (Refer to Figure 2 in Chapter 3)
3. The points m_1 and m_4 actually represent the fuzziness in the opinion of the analyst regarding the particular parameter. Thus, to determine these two points, the system prompts the analyst to enter a level of confidence in the answers given regarding the variation in the parameter value. The analyst must answer from amongst the following: 1) very high, 2) high, 3) more or less high, 4) more or less low, 5) low, and 6) very low. Depending upon the answer, the slopes of the fuzzy numbers are determined. For example, if the analyst were absolutely sure, then the slope would be zero, and the fuzzy number would, in effect, be reduced to an interval representing the variation possible in the cash flow value. On the other hand, if the analyst were absolutely unsure, the range of

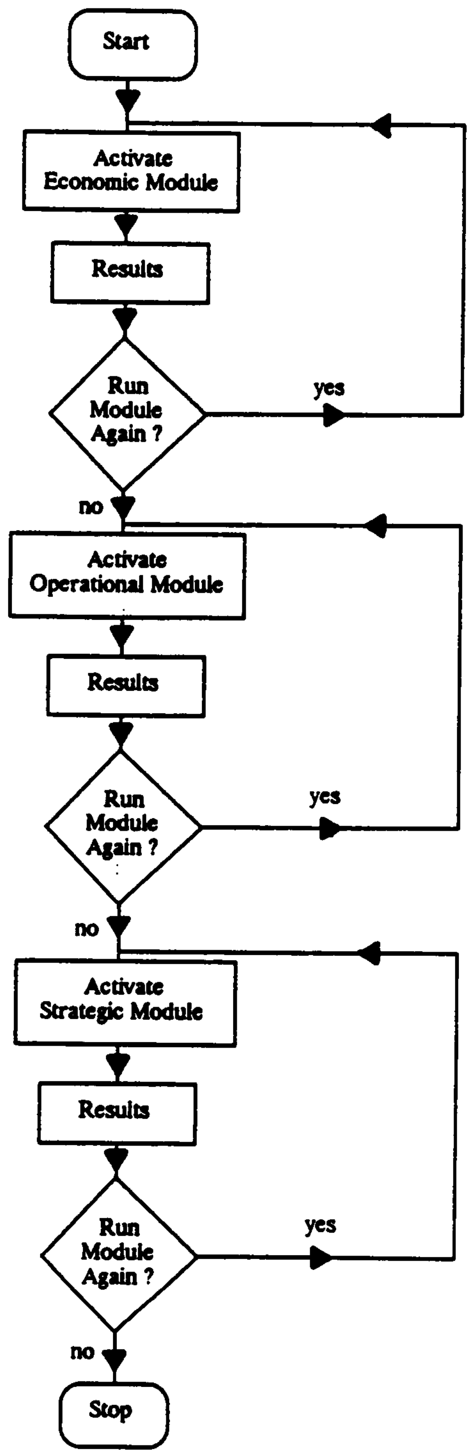

Figure 4: Conceptual Flowchart for the Model

the assigned values for m_1 and m_4 would be very large, thereby increasing the slope and the "fuzziness" of the number. The range is determined by applying a percentage variation to the percentage variations originally entered. The percentage variations that the model associates with the six levels of confidence given above, are presented in Table 1. The analyst is, however, given the opportunity to change these values if so desired. It may be noted at this point that the analyst is limited to a maximum percentage variation of 100% associated with the levels of confidence. This limitation ensures that the fuzzy number does not exist across zero, thereby enabling simplicity in calculation.

This algorithm is depicted by means of a flowchart in Figure 5. It provides a simple, yet efficient way to model trapezoidal fuzzy numbers.

4.3 The Structure of the Economic Module

The working of the economic module can be described step by step as follows:

1. The analyst is prompted for the initial investment amount. Since the initial investment is considered deterministic in nature in this model, it is entered as a crisp number.
2. The system then prompts the analyst to enter a base value for the interest rate. This base value is then used to model the interest rate as a fuzzy number, in accordance with the algorithm discussed in the previous section.
3. Once the interest rate has been modelled as a fuzzy number, the analyst is prompted for the project life. The model is limited to crisp numbers for the project life. This limitation

Table 1: Percentage Variations Internally Associated with Levels of Confidence

Level Of Confidence	Percentage Level
Very high	0.00 %
High	20.00 %
More or Less High	40.00 %
More or Less Low	60.00 %
Low	80.00 %
Very Low	100.00 %

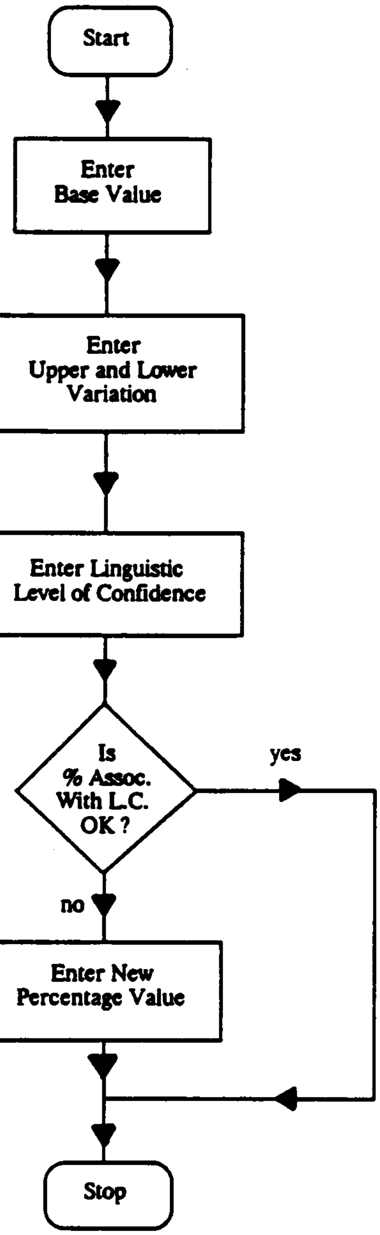

Figure 5: Conceptual Flowchart for Modelling Fuzzy Numbers

was imposed to keep the computational burden low, since fuzzy project life requires a tremendous increase in the mathematical complexity of the model.

4. The salvage amount is entered next. Using the value entered as the base, the salvage value is also modelled as a fuzzy number.

5. Now, the analyst is asked to enter the various cash flows and their times of occurrence. The analyst has the option of entering them in the form of regular annuities or as single cash flows. The module first prompts the analyst for all the uniform flows and their starting and ending years, and once all the uniform flows have been entered, the module asks for the single cash flows and their times of occurrence. The cash flow amounts are all modelled as fuzzy numbers. Additionally, the analyst may also enter any possible variations to the times of occurrence of the cash flows, although the variation in time of occurrence is only taken into account for the calculation of the NPV. The times of occurrence are modelled as fuzzy numbers in a slightly different fashion from the other variables. The difference is that the times of occurrence are not assigned an interval. The analyst is asked when the cash flow can occur if earlier than originally specified, and when it can occur if later than originally specified. The original value is then taken as the peak with a possibility of one, and the values specified on either side are taken as the possibility zero. Thus, the fuzzy number to represent the time of occurrence of a cash flow that was expected in year four, but could occur in year three or five would be (3, 4, 4, 5). A graph of the membership function of this triangular fuzzy number was shown in Figure 2.

6. Once all the cash flows have been entered, the fuzzy payback and NPV for the project are calculated. The results are then written into an output file.

A flowchart depicting the functioning of the economic module is shown in Figure 6. The economic module utilizes an exact algebraic formula for fuzzy addition, and approximate algebraic

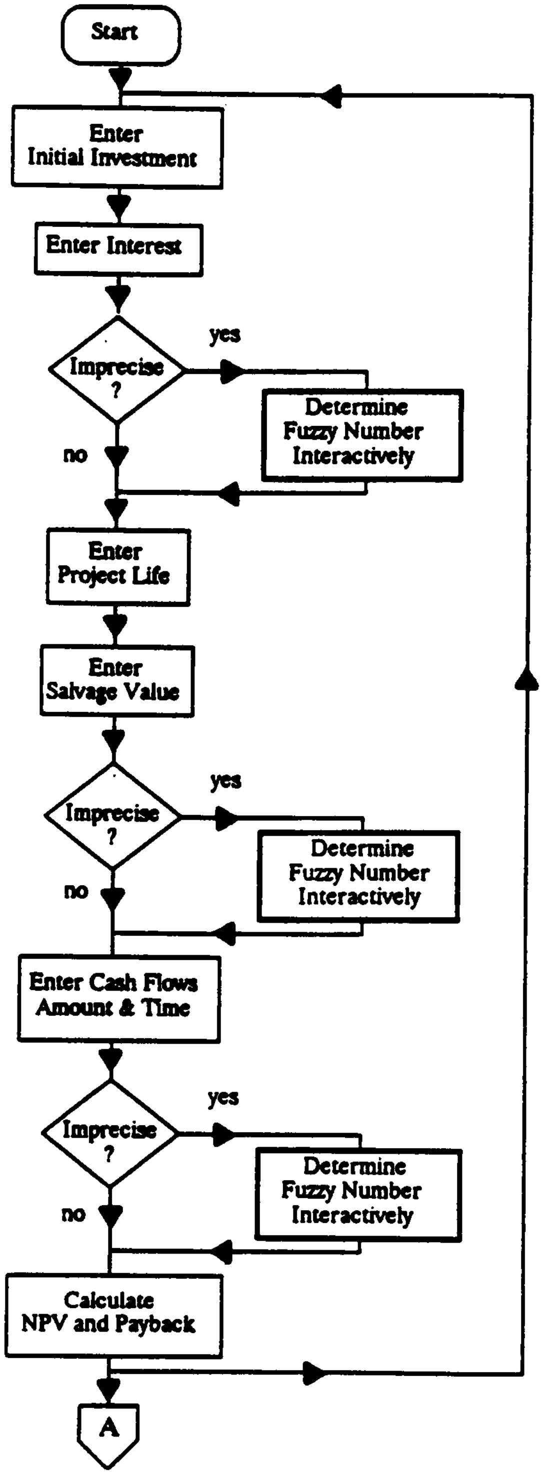

Figure 6: Conceptual Flowchart for the Economic Module

formulae for multiplication and exponential in the calculation of the results. These approximate formulae are tabulated in Table 2.

4.4 The Structure of the Operational Module

The various steps in the functioning of the operational model are described below:

1. The analyst is first asked the total number of attributes that are to be considered by the operational module. The analyst is limited to a maximum of eleven attributes. [15]
2. Next, the analyst is prompted for the name of the first attribute.
3. The analyst is then queried as to whether the rating and weight of the attribute will be described numerically or linguistically. The rating may be defined as the extent to which that particular attribute contributes to the final objective, whereas the weight is the extent to which that particular attribute is important to the final objective.
4. If the analyst opts for numerical input, there is provision for entering the rating and weight on a scale of zero to 100 or on a self-defined scale. If the latter is chosen, then the values are normalized by the model to a scale of zero to 100. The values entered are then taken as the base values and the ratings and weights are modelled as fuzzy numbers by the procedure described previously. On the other hand, if the analyst opts for linguistic input, a choice of six quantifiers is provided. These quantifiers are listed in Table 3, along with their internal fuzzy number representation. The same quantifiers and values are used for both the rating and the weight.
5. The procedure from Steps 2 to 4 is continued until all the attributes have been considered. The project desirability from the operational viewpoint is then calculated and written into

Table 2: Fuzzy Algebraic Approximations Used In the Computer Model

Operation	Result	Conditions
$m^* - n^*$	$(m_1 - n_1,\ m_2 - n_2,\ m_3 - n_3,\ m_4 - n_4)$	all m^* and n^*
$m^* \times n^*$	$(m_1 \times n_1,\ m_2 \times n_2,\ m_3 \times n_3,\ m_4 \times n_4)$	$m^* > 0, n^* > 0$
$m^* \div n^*$	$(m_1 \div n_1,\ m_2 \div n_2,\ m_3 \div n_3, m_4 \div n_4)$	$m^* > 0, n^* > 0$
$(m^*)^{n^*}$	$(m_1^{n1},\ m_2^{n2},\ m_3^{n3},\ m_4^{n4})$	$m^* \epsilon\ [1,\infty],\ n > 0$
$(m^*)^{n^*}$	$(m_1^{n4},\ m_2^{n3},\ m_3^{n2},\ m_4^{n1})$	$m^* \epsilon\ [1,\infty],\ n < 0$

where $m^* = (m_1, m_2, m_3, m_4)$

$n^* = (n_1, n_2, n_3, n_4)$

Table 3: Internal Representation of Linguistic Quantifiers

Operational Module

Quantifier	Associated Fuzzy Number
Very High (Very Important)	(80, 90, 90, 100)
High (Important)	(65, 75, 75, 85)
More or Less High (More or Less Imp.)	(50, 60, 60 ,70)
More or Less Low (More or Less Unimp.)	(35, 45, 45, 55)
Low (Unimportant)	(20, 30, 30, 40)
Very Low (Very Unimportant)	(5, 15, 15, 25)

Strategic Module

Quantifier	Associated Fuzzy Number
Very High (Very Important)	(75, 85, 90, 100)
High (Important)	(60, 70, 75, 85)
More or Less High (More or Less Imp.)	(45, 55, 60 ,70)
More or Less Low (More or Less Unimp.)	(30, 40, 45, 55)
Low (Unimportant)	(15, 25, 30, 40)
Very Low (Very Unimportant)	(0, 10, 15, 25)

an output file. Two values are written into the file -- a fuzzy number representing the project desirability on a scale of zero to 100 and its linguistic interpretation. The reconversion of the fuzzy number into a linguistic value is discussed in a subsequent section.

6. After the project desirability has been calculated, a sensitivity analysis is automatically made. This analysis changes the individual values for the rating and weight for each alternative and then recalculates the project desirability. The results from this analysis are also written into the output file. Given these values, the analyst is able to predict how the project viability would change in case the input values were changed. A detailed description of the sensitivity analysis is presented later in this chapter.

A flowchart depicting the functioning of the operational module is shown in Figure 7. The fuzzy algebraic approximations used in the operational module are multiplication and division. These are tabulated in Table 2. The functioning of the sensitivity analysis and the method of reconversion of the fuzzy numbers into linguistic values is discussed later in this chapter, since these discussions are common to both of the multi-attribute modules.

4.5 The Structure of the Strategic Module

The strategic module has essentially the same structure as the operational module. The major difference is that the strategic module handles only linguistic attributes. The analyst thus provides the rating and weight for each attribute by choosing from a set of linguistic quantifiers. The set of linguistic quantifiers is the same as in the operational module. However, the internal representation of these quantifiers is different. They have an increased fuzziness attached to them,

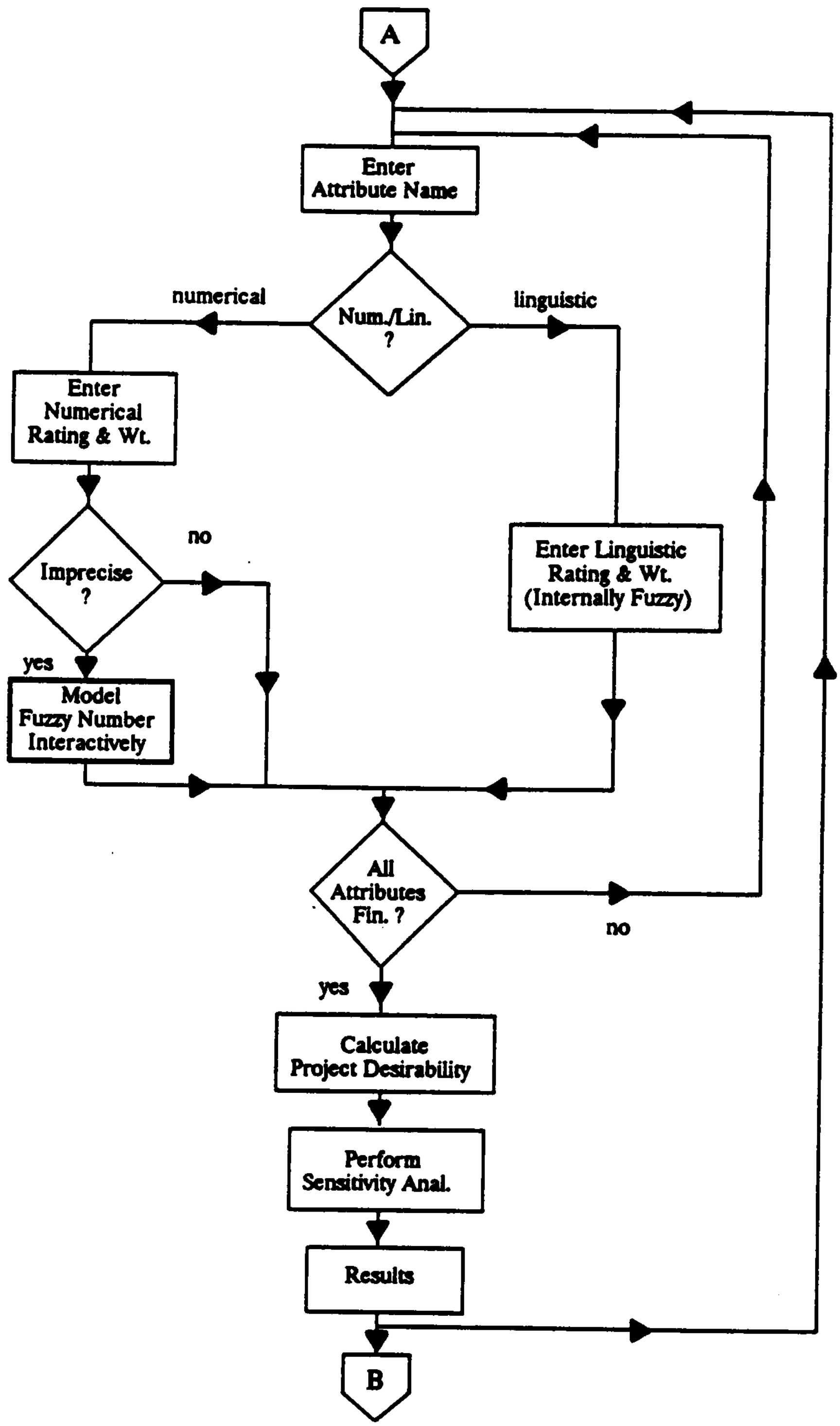

Figure 7: Conceptual Flowchart for Operational Module

the justification for which lies in the fact that the strategic module handles intangible benefits that are realizable at more distant points in time. The representations are tabulated along with the representations for the linguistic quantifiers in the operational module in Table 3.

A flowchart depicting the functioning of the strategic module is shown in Figure 8. The algebraic approximations used are the same as in the operational module. These approximations are tabulated in Table 2, and the sensitivity analysis and the method of reconversion are discussed in later sections in the chapter.

4.6 Reconversion of Fuzzy Numbers into Linguistic Terms

The reconversion of fuzzy numbers employs a concept that is analogous to the mean of the fuzzy number [13]. Since the weighted sums for the alternatives from both the operational and the strategic module are trapezoidal numbers, it is a simple matter to calculate the area under the graph. This is especially so since, being normal, the fuzzy number has a possibility level of 1 between the points m_1 and m_2. To calculate the "mean" of the fuzzy number the following steps are followed (Refer to Figure 9):

1. The total area under the graph is first calculated. This is simply the area of two triangles and one rectangle. The heights of the triangles and rectangle are one, so the area is completely defined by the four numbers that comprise the fuzzy number, m_1, m_2, m_3, and m_4.
2. The area determined is then halved.
3. The number is then mapped onto the original area, to determine the exact point on the

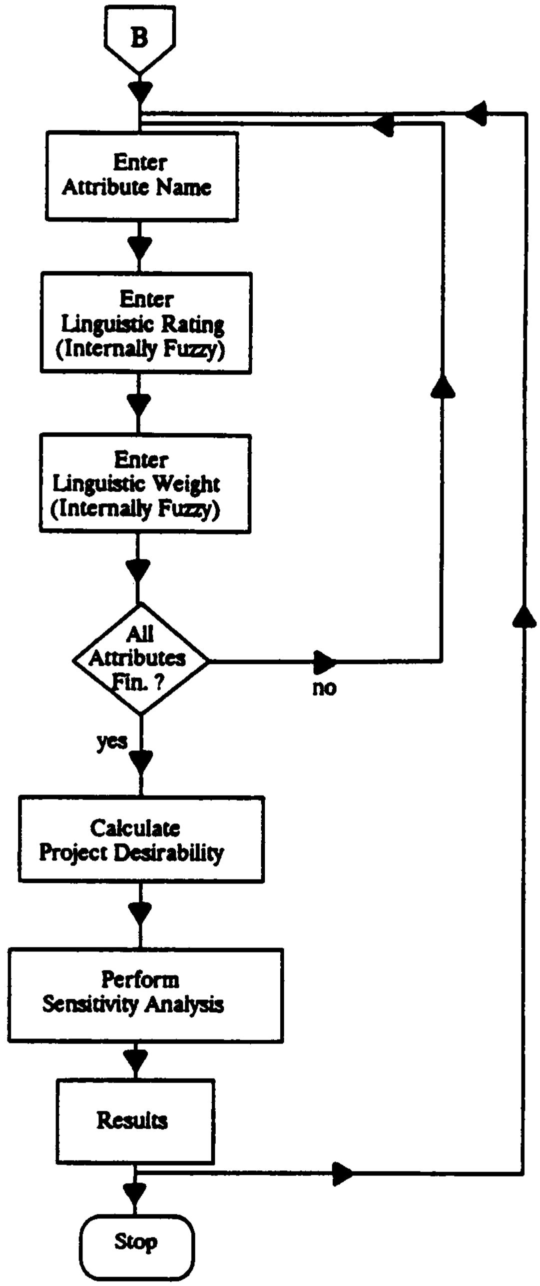

Figure 8: Conceptual Flowchart for Strategic Module

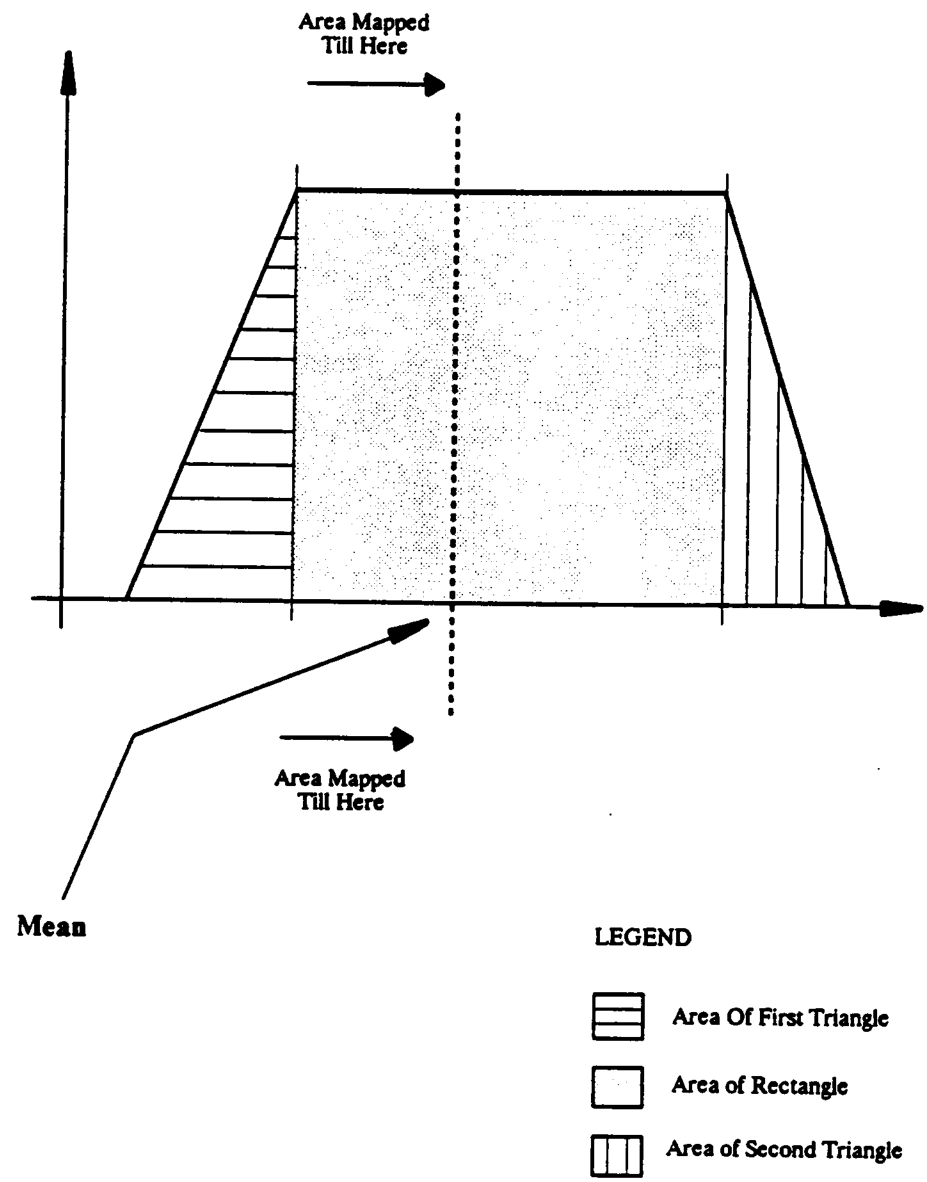

Figure 9: Reconversion of Fuzzy Numbers into Linguistic Quantifiers

mantissa, where the halved area finishes. This value on the mantissa is the mean of the fuzzy number.

4. Once this mean has been determined, the next step is to determine into which of six intervals this number falls. Each of these intervals represent one of the six linguistic quantifiers that were used by the analyst to define the linguistic attributes in the operational and strategic modules. The linguistic quantifier corresponding to the interval in which the number falls is then assigned to the number as its linguistic equivalent.

4.7 Sensitivity Analysis

The sensitivity analyses performed in the two multi-attribute modules is the same. It should be noted that these analyses are based on engineering economy models rather than on statistical models. Once the project desirability has been calculated, the modules automatically run the sensitivity analyses. The ratings and weights for the individual attributes are varied and for every variation, the project viability is recalculated. If the attribute is numerical (in the operational module only), the values are varied over a scale of zero to 100. The values used are the numerical ones that represent the six linguistic quantifiers internally, since these values provide a good symmetry over the entire scale. Thus for each numerical attribute, twelve new project viabilities are calculated, six corresponding to variations in the rating, with weight kept constant at the value specified by the analyst, and six corresponding to variations in the weight, with the rating kept constant at the value specified by the analyst. If the attribute is linguistic, then the project viability is simply calculated for each of the six linguistic quantifiers, for the rating and the weight. Therefore, for linguistic attributes as well, twelve new project viabilities are calculated for each attribute, six by varying the rating and six by varying the weight.

4.8 Software/Hardware Considerations

High level computer languages such as FORTRAN, PASCAL, and BASIC, have traditionally been used in the development of computer models like the one proposed here. However, they have inherent limitations with regard to structuring and flexibility that either limit the scope of the model or make it cumbersome to use. This becomes all the more apparent when they are compared to a language like "C," which has in recent times become quite popular. It has an impressive degree of structuring capability and can interface with almost all other computer languages. This is important when considered from the viewpoint of being able to interface two programs written in different languages without having to change the entire code of one. Therefore, this model has been developed in "C." It is implemented on a desktop PC, keeping in mind the popularity of this machine in today's business environment.

4.9 Summary

The level of programming sophistication achieved was somewhat limited. However, the computer model does provide promising results (See Chapter 5) and as such provides a sound basic structure for any future development. This is greatly aided by the fact that the concept of modular programming has been followed as diligently as possible. The use of "C" as the programming language proved to be a good decision, because such "C" attributes as structures and pointers greatly facilitated the programming task, while at the same time permitting the development of the model with maximum flexibility for future enhancement in mind. The next chapter develops a hypothetical example that is then used to demonstrate the various aspects of the computer model.

5. A Hypothetical Example

5.1 Introduction

In this chapter, a hypothetical example is first developed and then run using the computer model. The intent is to highlight the chief merits of the model. The example is adapted from a real life case study. It therefore closely approximates a real life situation, but all of the associated data are completely hypothetical. It involves a manufacturer of watch dials in the process of deciding between two alternatives systems to replace part of its production line. The economic data associated with the example were fabricated in such a way as to be able to have some imprecision attached to them. Both the alternatives involve high technology, and therefore are shown to have many non-economic tangible and intangible benefits, some of which are typically ones that an analyst might want to define linguistically. The example thus provides a means of demonstrating every aspect of the model. It may be noted that the discussion and interpretation of the given data, and thereby the results may change somewhat from analyst to analyst.

5.2 The Case of the Dial Manufacturer

A manufacturer of high precision ornamental watch dials has been experiencing difficulties in its production setup that have severely damaged its position in the market. When the firm was established, some six years ago, machines were purchased that seemed like sound investments from an economic standpoint, and indeed they were for the first couple of years. The machines were mostly manual and very labor intensive, but the watch market was not very demanding, so the production rate was sufficient to satisfy the monthly market demand of 75,000 dials, and the future looked promising. There was a small quality problem because of dust and other related factors spoiling the face finish. But most of the bad dials could be reworked, and even though this was not an ideal situation, it was not something the company was worried about. After the first two years, however, the situation changed drastically because competitors, using high technology equipment were producing dials of superior quality, faster and more efficiently. A more developed sales network and market goodwill balanced the technological imbalance for some time. Slowly, however, the competitors started gaining ground, aided by a substantial increase in demand for high quality dials.

Today, the situation is at the point where the future of the company is in jeopardy. Market position and company image are at all-time lows, and employee morale is at an ebb. All attempts at more stringent quality control regulations have failed, and the management has reached the conclusion that an investment in new technology is imperative.

There are a number of major dial types. The firm however is manufacturing only printed type dials. The whole process of making these dials involves five steps. The raw material is in the form of brass disks that are first cleaned, buffed and plated with silver and then gold to prevent oxidation and tarnishing. Two small pins, called "feet," that hold the dial in place in a watch are then glued. Subsequently, the dials are coated by a special lacquer to achieve the desired face color and finally printed before they are sent to inspection. Sometimes, instead of lacquering, a special process called "brushing" may be required, but demand for brushed dials is very limited. A very controlled environment is required to keep the dust problem to a minimum. Also, very careful material handling is required. The slightest mishandling can spoil the face finish causing the dial to be rejected. Currently, every stage of the manufacturing cycle requires a lot of manual handling of the dials. Each dial is individually cleaned and polished by means of dial holders and buffing wheels. The plating is done by putting dials into a basket and hanging it by a vibrating hook within the bath. The lacquering is done by a worker using a manual spray gun inside a cabin with constant air filtering to keep out dust. After lacquering, the dials are taken to be printed, where they are individually placed on the printing machine and printed. They are then sent for inspection. The dials are transported by special perforated steel plates that use the dial feet to hold the dial in place.

The quality problem is caused by microscopic dust settling on wet dials, workers handling the dials before the lacquer has completely set, and by uneven lacquering or printing. Currently the rejection rate is about 20%. Most of the rejected dials can be reworked but this is at the expense of the net production rate. Currently, the process line is capable of producing 100,000 dials per month. Consequently, only about 80,000 marketable dials are produced every month. Marketing estimates that given good quality dials with reasonably short delivery schedules, they can sell about 150,000 dials a month, and the market is expected to increase to 500,000 dials a month in the next seven to 10 years. The net cost per dial is about $ 0.62. However, reworking a dial costs about $ 0.20, and a dial can undergo a maximum of two reworks before it is discarded altogether. Given the current rejection and rework rate, the net cost per dial goes up to about $ 0.68. The average selling price per dial is about $ 0.71, so the reworking cost reduces the profit margin significantly. The average turn-around-time for an order is about six months currently. The floor space used by the current machines is about 300 square feet. The company does not have an immediate space problem, but would like to conserve space as much as possible.

Management is convinced that an answer to most of the company's problems may lie in introducing a higher level of automation. Although it would like to refurbish the entire production line, immediate financial constraints limit this. Therefore, having discussed the problem at length with the engineering department and having identified the critical areas, lacquering through printing, it has decided to tackle this area first. Engineering has consequently scouted the market for available technology. The chief bases for comparing the systems have been the economics, quality improvement, production volume, capability to increase production, turn around times from receipt of order to delivery, compatibility with the existing equipment, flexibility with regard to technological upgrade, and maintainability. After careful consideration of the advantages and disadvantages of every system, the choice has been narrowed down to two alternatives.

5.2.1 Alternative 1

The first alternative is a set of machines consisting of an automatic spray lacquering machine, a steel belted mini conveyor, and an automatic printing machine. The lacquering machine consists of a small cabin with a shuttle running through it. This shuttle carries a tray of dials, very similar to the ones currently in use, from a small input port on the side to the center of the cabin where the dials are sprayed by means of a nozzle moving to and fro by pneumatic force. Once the spray is complete, the dials are carried by the shuttle to the output port where the trays are put onto the conveyor automatically for transporting to the printing area. Since the spraying gets done inside a cabin without human presence, and the time set up is automatically adjusted to allow sufficient time for the dials to dry before they are put onto the conveyor, the dust problem is nonexistent. The printing machine consists of the printing mechanism and a circular indexed bed that has twelve fixtures placed symmetrically around it. These fixtures simply hold the dial in place by the dial "feet," while the printing is being done. A worker is needed to unload trays as they arrive on the conveyor and then to use a special pneumatic tool to load and unload individual dials to and from the fixtures on the bed. The system is capable of a monthly production of approximately 175,000 dials with a rejection rate of 7%. In this case too, the rejected dials can be reworked, at approximately the same cost as the current setup, but the reduced rejection rate reduces net dial cost to approximately $ 0.64. The production rate is really limited only by the printing machine, because the lacquering machine can produce up to 300,000 dials a month. Therefore when higher production is required, a second printing machine can be easily integrated into the setup. Setting the machines up for a different kind of dial takes about four to five hours. It is estimated that, with this system installed, turn around time will be reduced to less than two months. The entire system costs $ 225,000. It is estimated to have additional operating and maintenance costs in the range of $ 12,000 to $ 13,000 per year. Savings due to reduced rejections are estimated to be about $ 48,000 per year. Additional revenue due to increased production, by 50,000 dials a month, is estimated at $ 36,000 per year. It is possible, however, that the increase in production may not be realized until the second year of operation. Although labor will be reduced, there are no plans of laying off any labor, so there will be no savings there. The system does not require specialized maintenance or training of personnel. It can be considered to have an economic life of ten years, with a salvage value of $ 9,000 to $ 10,000 depending on the condition of the system. The system is capable of being integrated with other state-of-the-art technology to a limited extent. It requires a floor area of approximately 200 square feet.

5.2.2 Alternative 2

The second system is a computer-controlled, special-purpose integrated manufacturing cell. It was developed specifically for the dial industry and introduced in the market less than two months ago. It consists of a single unit that performs both the lacquering and the printing functions. The dials are fed into a special feeder and the computer is used to program the machine for the face color and type of printing required. The machine performs the lacquering by a layering rather than a spraying method. It is capable of being switched to twelve different colors almost immediately, as long as the different lacquer cartridges are loaded. Also, the machine can be "ready" to change to six different printing designs at any given time. This machine has a monthly capacity of over 300,000 dials. It is capable of complete integration with other state-of-the-art machinery. Rejection rate is less than 5%, but rejected dials cannot be reworked. The net cost per dial is estimated at $ 0.63.

The machine is more expensive than the first system. It has a price tag of $ 315,000. The additional operating and maintenance costs are estimated to be approximately $ 17,000 per year. Savings from reduced rejections will be about $ 60,000 per year. Additional revenue from increased production is estimated at $ 48,000 and this production increase may be expected from the first year onwards. It has an estimated economic life of ten years, with an estimated salvage value of $ 15,000. The machine requires some special training for the operator and this training is estimated to cost $ 1,500 for the first year only.

Maintenance requirements are also very specialized, but the vendor has a good record of keeping maintenance schedules in case of a system crash. The floor space requirements are about 150 square feet. The order turn around time can be reduced to less than a month. This vendor, being a specialist manufacturer of such machines for the watch industry, makes other machines too, which the company may want to purchase at a later date to refurbish the rest of their process line. These machines are completely compatible with each other. In fact, it is the vendor's contention that at the highest level of automation, their machines can together form a completely automated line requiring no direct human interface. The particular machine in question, therefore, has a very high degree of upgradability and capability to interface with other state-of-the-art in technology. Also, the vendor has survey statistics to ratify the claim that dials made on this machine are sharper in quality than any other machine on the market.

Engineering is more favorably inclined towards the second alternative, because they perceive the intangible benefits of great future value to the company. They think that using state-of-the-art technology would not only be useful towards the immediate aim of improved quality and strict upkeep of production schedules, but also of long-term goals like easy upgrade to new technologies, better company image within the watch industry, better worker morale, and an increased competitive edge.

However, top management, hard pressed for immediate finances, is more inclined towards the first alternative due to its more attractive economic attributes. Top management recognizes the other intangible benefits, but does not regard them as being important at this time, when compared to the additional investment required. Engineering feels that this may be due to lack of a means of presenting the benefits to management in the proper form. They would like to be able to show the intangible as well tangible benefits for each project side by side, while at the same time depicting some measure of the inaccuracy or imprecision that is inherently present in the future estimates. It is engineering's opinion that having depicted such results they stand a good chance of winning their case. The company's required rate of return for any given proposal, taking into account all its cost of capital, is 20% before taxes. The data for the two competing alternatives and other relevant data is depicted in tabular form in Tables 4 and 5.

Table 4: Economic Data for the Hypothetical Example

Economic Data

	Alternative 1	Alternative 2
Initial Investment ($)	225,000.00	315,000.00
Salvage Value ($)	10,000.00	15,000.00
Additional Operating & Maintenance Costs ($/annum)	13,000.00	17,000.00
Training Costs ($/Yr. 1)	0.00	1,500.00
Savings from Reduced Rejection ($/annum)	48,000.00	60,000.00
Additional Revenue from Increased Production ($/annum)	36,000.00	48,000.00
MARR (Before Tax) (%)	20.00	20.00
Economic Life	10 yrs.	10 yrs.

Table 5: Non-Economic Data for Hypothetical Example

Non-Economic Data

	Alternative 1	Alternative 2
TANGIBLE		
Floor Space Reqd.	200 sq. ft.	150 sq. ft.
Setup Time	app. 4-5 hrs.	immediate
Turn-Around Time	about 3 months	less than 2 months
Capacity for Production Increase	up to 300,000	up to 300,000
INTANGIBLE		
Dial Quality	good	excellent
Compatibility with Existing Setup	high	high
Training Reqd.	not specialized	very specialized
Flexibility for Technological Upgrade	high	very high
Company Image	will go up	greatly enhanced
Competitive Edge	average	very high
Worker Morale	high	high

5.3 Discussion of Attributes

Each attribute listed in Table 4 and Table 5 as relevant to the example developed, is discussed below for the purpose of identifying the values to be entered in the model for that attribute. Tables 6, 7, 8, 9 and 10 list the values that were actually entered in the economic, operational, and strategic modules based on the discussion below.

5.3.1 Economic Data

Initial Investment: The initial investment is assumed to be deterministic, and is therefore not modelled as a fuzzy number. It is therefore entered exactly as given, i.e., $ 225,000 for the first alternative and $ 315,000 for the second alternative.

Salvage Value: The salvage value is given as $ 10,000 for alternative 1 and $ 15,000 for alternative 2. However, there is usually a significant amount of uncertainty regarding the realization of this salvage value completely. This is more so in the case of machines and equipment that is specialized for a certain function. This is so because machines that are more general in their setup usually find low-end buyers who are thinking of buying cheap machinery and using parts from different machines to develop their system. Consequently, even though it has the possibility of a higher salvage amount, the second alternative's salvage value would be subject to a higher degree of imprecision. The values for the salvage amount are thus input as shown in Table 6. The 0% upper variation represents a ceiling on the salvage value of $ 10,000 and $ 15,000 respectively for the two alternatives.

Additional Operating and Maintenance Costs: The additional operating and maintenance costs for the second alternative would have a higher element of uncertainty or imprecision associated with them. The basis for this premise is that since the second machine is new technology, estimating its operating and maintenance costs is more of a subjective judgment. Therefore, even though the variation expected in the operating and maintenance costs is taken to be approximately the same, the level of confidence for the second one is lower for the second machine. The values entered are shown in Table 6.

Savings from Reduced Rejection: The second alternative is an integrated machine, and therefore is less prone to external factors on its production capability. Consequently, the second machine is less liable to have variations in its production and quality level. At the same time, however, for the same reasons as for operating and maintenance costs, the level of confidence in the assigned values is lower for the second alternative. The values entered are shown in Table 6.

Revenue from Increased Production: This aspect of the data can be considered to have a significant amount of imprecision and uncertainty attached to it. The estimates of increased market demand are based on statistical data from previous years and are therefore only a projection. Additionally, at the present moment, given the company's current financial and technical health, it would be wise to discount increased production levels, and their estimated time of occurrence. It can be said, however, that it would be relatively easier to increase production levels using the second alternative, assuming that it is well established into the production setup and is providing the company with the promised savings from reduced rework. The values entered for both the alternatives are listed in Table 6. (The imprecision in the time of occurrence is not listed in the table. This imprecision was taken to be 0 on the lower side and 1 year on the higher side for each year).

Table 6: Input Values for the Economic Module

	Attribute	Base Value	Lower Variation (%)	Upper Variation (%)	Confidence Level
	MARR	20	5	0	very high
	Project Life	10	0	0	-
Alternative 1	Initial Investment	225,000	0	0	-
	Salvage Value	10,000	15	0	high
	Operating and Maintenance Costs	13,000	10	10	very high
	Savings from Reduced Rejections	48,000	10	0	high
	Revenue from Increased Production	36,000	20	0	more or less high
Alternative 2	Initial Investment	315,000	0	0	-
	Salvage Value	15,000	15	0	more or less high
	Operating and Maintenance Costs	17,000	15	15	more or less high
	Savings from Reduced Rejection	60,000	15	0	high
	Revenue from Increased Production	48,000	20	0	high
	Training Costs (Yr. 1)	1,500	10	10	high

Minimum Attractive Rate of Return: The company has established a reasonably high before tax MARR. The reason may be attributed to high interest rates set by financial institutions for loans money to the company, in light of its poor financial health. It is estimated that the MARR would probably never be higher than 20% and therefore, that is taken as its upper bound, i.e., the upper variation is considered to be zero. The lower variation is taken as 5%. The level of confidence in these values is taken to be high.

Project Life: The project life is entered as given in the data, since the model does not provide for variation in project life.

5.3.2 Non-Economic Data

Floor Space Required: This attribute is defined numerically. Since the available space is 300 sq. feet, both the alternatives are providing some space saving. However, to be able to distinguish between the two attributes, a common scale must be established. Therefore, a numerical scale representing floor space saved is defined. The maximum value on the scale is defined as 200 and the minimum as zero. The ratings and weights are shown in Tables 7 and 8. The percentage variations and level of confidence have their basis in the fact that the space requirements are reasonably well defined. The company would like to conserve space, to leave room for further expansion, but does not consider this an imperative requirement. This argument justifies the values input for the weight. This attribute is considered a short-term benefit and is therefore considered an operational benefit.

Setup Time: This attribute is considered as an important operational benefit, since it has a

Table 7: Numerical Input Ratings for the Operational Module

	Attributes	Base Value	Lower Variation (%)	Upper Variation (%)	Confidence Level
Alternative 1	Floor Space Required (0-300)	100	5	10	very high
	Setup time (0-100)	50	20	0	high
	Turn-Around Time (0-180)	60	40	0	high
	Capacity for Increasing Production (0-500,000)	150,000	10	10	more or less high
Alternative 2	Floor Space Required (0-300)	150	5	10	very high
	Setup time (0-100)	95	20	0	high
	Turn-Around Time (0-180)	120	25	0	more or less high
	Capacity for Increasing Production (0-500,000)	150,000	10	10	high

Note: Scale for each attribute is given under attribute name

Table 8: Numerical Input Weights for Operational Module

Attributes	Base Value	Lower Var. (%)	Upper Var. (%)	Confidence Level
Floor Space Required (0-100)	40	10	10	more or less high
Setup Time (0-100)	70	5	0	high
Turn-Around Time (0-100)	80	5	5	very high
Capacity for Increasing Production (0-100)	50	10	10	more or less low

Note: Scale for each attribute is given under attribute name significant bearing on the lot sizes, and thereby on the variety of dials that can be produced in a given time span. The ratings and the weights are defined on scales of zero to 100, as shown in Tables 7 and 8. The alternatives are rated with the underlying assumption that an entire eight-hour shift used for setup should be considered as zero on the scale and immediate setup as 100. The second alternative is assigned a lower level of confidence, because the only substantiating factor for the setup time given is the manufacturer's specification sheet. Also, it is very dependent on the training of the operator. The weighting is assigned keeping in mind the importance of this attribute to the company.

Turn-Around Time: This is an operational benefit as well, and the high importance of this attribute is reflected in the weight assigned, as shown in Table 8. With the current turn-around time being six months, the attribute is rated as being a reduction in the turn-around time. Thus the maximum on the scale is taken as 180 (number of days) and minimum as zero (Refer to Table 7).

Capacity for Increased Production: The attribute is considered as a percentage of the maximum increase envisaged in the market in the next five years. Thus, the maximum on the scale is taken as 500,000 and the minimum as zero. The first alternative is given a higher level of imprecision since, to increase its production, it requires purchasing more equipment etc., in contrast to the other alternative, which, assuming a satisfactory initial stage, can increase production more easily. The attribute is considered in the operational module, and all values are depicted in Tables 7 and 8.

Dial Quality: It was decided to enter this attribute in linguistic terms. It is considered as an important short-term benefit for the company, as long as the rejection rate is reduced. For both alternatives, it is not an essential requirement. That therefore defines the weight. The rating is shown in Table 9.

Compatibility with Existing Setup: The second machine is essentially a stand-alone machine, until more equipment is purchased. The feeders for this machine are very different from the trays being used at the present moment and neither are interchangeable. Thus, the second machine has a relatively lower rating than the first alternative, which uses plates very similar to, and interchangeable with, the ones used presently. The ratings and the weighting that are used to define this are listed in Table 9.

Training Required: The second alternative definitely requires more specialized training which is not preferable. However, the company is not unduly concerned about the training requirements, since it realizes that any new technology would require some sort of special training and is therefore prepared, if need be, to hire more skilled personnel. Consequently, it is not assigned a very heavy weight as tabulated in Table 9.

Flexibility for Technological Upgrade: Having burnt its fingers in the past, the company considers this an almost essential requirement. It has opted to consider this attribute in linguistic terms, and it is considered a long-term strategic benefit. The input values to the model are listed in Table 10.

Company Image: This attribute also is easier defined in linguistic terms. It is considered a long-term strategic benefit. Since the second alternative involves state-of-the-art technology, the belief is that the company's image will be greatly enhanced if it decides to invest in it. The importance of this benefit cannot be overemphasized, but at the same time it is not an essential requirement. The ratings and the weight defined are shown in Table 10.

Competitive Edge: This strategic benefit is of vital importance to the company. The dial market already has almost cut-throat competition, and to be able to survive in it requires a sharp

Table 9: Linguistic Input Values for the Operational Module

Attributes	Rating		Weight
	Alternative 1	Alternative 2	
Dial Quality	more or less high	very high	more or less low
Compatibility with Existing M/Cs	high	more or less high	more or less high
Training Required	high	high	more or less low

Table 10: Linguistic Input Values for Strategic Module

Attribute	Rating		Weight
	Alternative 1	Alternative 2	
Flexibility for Technological Upgrade	more or less high	very high	high
Company Image	more or less low	very high	high
Competitive Edge	more or less low	high	very high

competitive edge. The second alternative, given its overall flexibility, has a better rating than the first alternative. The values used in the model are shown in Table 10.

Worker Morale: As far as the workers go, both machines are expected to increase their motivation to approximately the same degree. In the light of the fact that it is only these two alternatives that the company wants to decide between, this attribute may thus be omitted from consideration.

5.4 Results from the Example

The results obtained from the computer model for the case study are listed below:

Alternative 1

1.	Fuzzy Payback	(4, 4, 4, 4)
2.	Fuzzy NPV ($)	(-6450.79, 27465.23, 81274.19, 83850.41)
3.	Operational Viability (Numerical)	(42.82, 48.52, 53.16, 58.90)
4.	Operational Viability (Linguistic)	more or less low
5.	Strategic Viability (Linguistic)	more or less low

Alternative 2

1.	Fuzzy Payback	(4, 4, 5, 5)
2.	Fuzzy NPV ($)	(-35887.48, 356.08, 74656.90, 75599.70)

3.	Operational Viability (Numerical)	(57.04, 62.19, 68.84, 74.23)
4.	Operational Viability (Linguistic)	more or less high
5.	Strategic Viability (Linguistic)	high

The sensitivity analyses resulting from the operational module and the strategic module are presented in Tables 11 through 16. For each attribute, the weight is assigned six values while keeping its rating the same as that entered by the analyst. The overall project viability for each of these six sets of values is then calculated. This is depicted in the first block of six value sets for each attribute. Then the sensitivity for that attribute's rating is also evaluated in the same fashion. This is depicted in the second block of values for that attribute. Thus, the sensitivity of the overall project viability toward the rating or weight of any attribute while keeping all other assigned values constant, is known.

Quite evidently, the entire set of results from the three modules provides a lot of useful information regarding both the alternatives. It is seen that from the economic point of view, the first alternative seems a better investment, since it has a more precise payback and a high, positive NPV with a lower possibility of falling to a negative value. However, the results of the operational and strategic modules indicate that the second alternative has much stronger non-economic benefits, which will be subsequently discussed. Effectively, the results provide a means of viewing each of the projects from a more informed perspective, as well as of comparing the two alternatives equitably.

Presented below is a more detailed discussion of the results from each of the three modules and a comparison of the two alternatives in the light of the results.

Table 11: Sensitivity Results for Alternative 1. (Depicting changes with respect to numerical attributes)

Attribute	Rating	Weight	Operational Viability
Floor Space	≈33.33	≈15.00	≈48.70
	≈33.33	≈30.00	≈48.13
	≈33.33	≈45.00	≈47.61
	≈33.33	≈60.00	≈47.13
	≈33.33	≈75.00	≈46.67
	≈33.33	≈90.00	≈46.25
	≈15.00	≈40.00	≈45.83
	≈30.00	≈40.00	≈47.37
	≈45.00	≈40.00	≈48.92
	≈60.00	≈40.00	≈50.46
	≈75.00	≈40.00	≈52.00
	≈90.00	≈40.00	≈53.55
Setup Time	≈50.00	≈15.00	≈48.29
	≈50.00	≈30.00	≈48.13
	≈50.00	≈45.00	≈47.99
	≈50.00	≈60.00	≈47.85
	≈50.00	≈75.00	≈47.73
	≈50.00	≈90.00	≈47.61
	≈15.00	≈70.00	≈42.57
	≈30.00	≈70.00	≈45.22
	≈45.00	≈70.00	≈47.87
	≈60.00	≈70.00	≈50.52
	≈75.00	≈70.00	≈53.16
	≈90.00	≈70.00	≈55.82
Turn-around	≈33.3	≈15.00	≈52.28
	≈33.3	≈30.00	≈51.09
	≈33.3	≈45.00	≈50.00
	≈33.3	≈60.00	≈49.01
	≈33.3	≈75.00	≈48.09
	≈33.3	≈90.00	≈47.25
	≈15.00	≈80.00	≈45.50
	≈30.00	≈80.00	≈48.61
	≈45.00	≈80.00	≈51.72
	≈60.00	≈80.00	≈54.83

Table 11 (cont.): Sensitivity Results for Alternative 1. (Depicting changes with respect to numerical attributes)

Attribute	Rating	Weight	Operational Viability
Turn-around	≈75.00	≈80.00	≈57.93
	≈90.00	≈80.00	≈61.93
Increasing Production	≈30.00	≈15.00	≈49.97
	≈30.00	≈30.00	≈49.55
	≈30.00	≈45.00	≈48.76
	≈30.00	≈60.00	≈48.02
	≈30.00	≈75.00	≈47.35
	≈30.00	≈90.00	≈46.72
	≈15.00	≈50.00	≈45.88
	≈30.00	≈50.00	≈47.81
	≈45.00	≈50.00	≈49.73
	≈60.00	≈50.00	≈51.66
	≈75.00	≈50.00	≈53.58
	≈90.00	≈50.00	≈55.51

Table 12: Sensitivity Results for Alternative 2. (Depicting changes with respect to numerical attributes)

Attribute	Rating	Weight	Operational Viability
Floor Space	~50.00	~15.00	~64.89
	~50.00	~30.00	~64.36
	~50.00	~45.00	~63.87
	~50.00	~60.00	~63.42
	~50.00	~75.00	~62.99
	~50.00	~90.00	~62.60
	~15.00	~40.00	~60.32
	~30.00	~40.00	~61.86
	~45.00	~40.00	~63.40
	~60.00	~40.00	~64.95
	~75.00	~40.00	~66.49
	~90.00	~40.00	~68.03
Setup Time	~95.00	~15.00	~60.78
	~95.00	~30.00	~61.80
	~95.00	~45.00	~62.74
	~95.00	~60.00	~63.60
	~95.00	~75.00	~64.39
	~95.00	~90.00	~65.13
	~15.00	~70.00	~51.80
	~30.00	~70.00	~54.45
	~45.00	~70.00	~57.09
	~60.00	~70.00	~59.74
	~75.00	~70.00	~62.39
	~90.00	~70.00	~65.04
Turn-around	~66.67	~15.00	~65.64
	~66.67	~30.00	~65.21
	~66.67	~45.00	~64.83
	~66.67	~60.00	~64.48
	~66.67	~75.00	~64.16
	~66.67	~90.00	~63.86
	~15.00	~80.00	~55.43
	~30.00	~80.00	~58.54
	~45.00	~80.00	~61.64
	~60.00	~80.00	~64.75

Table 12 (cont.): Sensitivity Results for Alternative 2. (Depicting changes with respect to numerical attributes)

Attribute	Rating	Weight	Operational Viability
Turn-around	~75.00	~80.00	~67.86
	~90.00	~80.00	~70.96
Increasing Production	~30.00	~15.00	~67.42
	~30.00	~30.00	~65.90
	~30.00	~45.00	~64.49
	~30.00	~60.00	~63.20
	~30.00	~75.00	~61.99
	~30.00	~90.00	~60.88
	~15.00	~50.00	~62.13
	~30.00	~50.00	~64.06
	~45.00	~50.00	~65.98
	~60.00	~50.00	~67.91
	~75.00	~50.00	~69.83
	~90.00	~50.00	~71.76

Table 13: Sensitivity Results for Alternative 1. (Depicting changes with respect to linguistic attributes from the operational module)

Attribute	Rating	Weight	Operational Viability
Dial Quality	more or less high	very low	more or less low
	more or less high	low	more or less low
	more or less high	more or less low	more or less low
	more or less high	more or less high	more or less low
	more or less high	high	more or less low
	more or less high	very high	more or less low
	very low	more or less low	more or less low
	low	more or less low	more or less low
	more or less low	more or less low	more or less low
	more or less high	more or less low	more or less low
	high	more or less low	more or less high
	very high	more or less low	more or less high
Compatibility with Existing M/C	high	very low	more or less low
	high	low	more or less low
	high	more or less low	more or less low
	high	more or less high	more or less low
	high	high	more or less low
	high	very high	more or less high
	very low	more or less high	more or less low
	low	more or less high	more or less low
	more or less low	more or less high	more or less low
	more or less high	more or less high	more or less low
	high	more or less high	more or less low
	very high	more or less high	more or less high
Training Required	high	very low	more or less low
	high	low	more or less low
	high	more or less low	more or less low
	high	more or less high	more or less low
	high	high	more or less high
	high	very high	more or less high

Table 13 (cont.): Sensitivity Results for Alternative 1. (Depicting changes with respect to linguistic attributes from the operational module)

Attribute	Rating	Weight	Operational Viability
Training Required	very low	more or less low	more or less low
	low	more or less low	more or less low
	more or less low	more or less low	more or less low
	more or less high	more or less low	more or less low
	high	more or less low	more or less low
	very high	more or less low	more or less high

Table 14: Sensitivity Results for Alternative 2. (Depicting changes with respect to linguistic attributes from the operational module)

Attribute	Rating	Weight	Operational Viability
Dial Quality	very high	very low	more or less high
	very high	low	more or less high
	very high	more or less low	more or less high
	very high	more or less high	more or less high
	very high	high	high
	very high	very high	high
	very low	more or less low	more or less high
	low	more or less low	more or less high
	more or less low	more or less low	more or less high
	more or less high	more or less low	more or less high
	high	more or less low	more or less high
	very high	more or less low	more or less high
Compatibility with Existing M/C	more or less high	very low	more or less high
	more or less high	low	more or less high
	more or less high	more or less low	more or less high
	more or less high	more or less high	more or less high
	more or less high	high	more or less high
	more or less high	very high	more or less high
	very low	more or less high	more or less high
	low	more or less high	more or less high
	more or less low	more or less high	more or less high
	more or less high	more or less high	more or less high
	high	more or less high	high
	very high	more or less high	high
Training Required	high	very low	more or less high
	high	low	more or less high
	high	more or less low	more or less high
	high	more or less high	more or less high
	high	high	more or less high
	high	very high	more or less high

Table 14 (cont.): Sensitivity Results for Alternative 2. (Depicting changes with respect to linguistic attributes from the operational module)

Attribute	Rating	Weight	Operational Viability
Training Required	very low	more or less low	more or less high
	low	more or less low	more or less high
	more or less low	more or less low	more or less high
	more or less high	more or less low	more or less high
	high	more or less low	more or less high
	very high	more or less low	high

Table 15: Sensitivity Results for Alternative 1. (Depicting changes with respect to linguistic attributes from the strategic module)

Attribute	Rating	Weight	Strategic Viability
Flexibility for Technological Upgrade	more or less high	very low	more or less low
	more or less high	low	more or less low
	more or less low	more or less low	more or less low
	more or less high	more or less high	more or less low
	more or less high	high	more or less low
	more or less high	very high	more or less low
	very low	high	low
	low	high	more or less low
	more or less low	high	more or less low
	more or less high	high	more or less low
	high	high	more or less high
	very high	high	more or less high
Company Image	more or less low	very low	more or less low
	more or less low	low	more or less low
	more or less low	more or less low	more or less low
	more or less low	more or less high	more or less low
	more or less low	high	more or less low
	more or less low	very high	more or less low
	very low	very high	more or less low
	low	very high	more or less low
	more or less low	very high	more or less low
	more or less high	very high	more or less high
	high	very high	more or less high
	very high	very high	more or less high
Competitive Edge	more or less low	very low	more or less low
	more or less low	low	more or less low
	more or less low	more or less low	more or less low
	more or less low	more or less high	more or less low
	more or less low	high	more or less low
	more or less low	very high	more or less low

Table 15 (cont.): Sensitivity Results for Alternative 1. (Depicting changes with respect to linguistic attributes from the strategic module)

Attribute	Rating	Weight	Strategic Viability
Competitive Edge	very low	very high	low
	low	very high	more or less low
	more or less low	very high	more or less low
	more or less high	very high	more or less high
	high	very high	more or less high
	very high	very high	more or less high

Table 16: Sensitivity Results for Alternative 2. (Depicting changes with respect to linguistic attributes from the strategic module)

Attribute	Rating	Weight	Strategic Viability
Flexibility for Technological Upgrade	very high	very low	high
	very high	low	high
	very high	more or less low	high
	very high	more or less high	high
	very high	high	high
	very high	very high	very high
	very low	high	more or less high
	low	high	more or less high
	more or less low	high	high
	more or less high	high	high
	high	high	high
	very high	high	high
Company Image	very high	very low	high
	very high	low	high
	very high	more or less low	high
	very high	more or less high	high
	very high	high	high
	very high	very high	very high
	very low	high	more or less high
	low	high	more or less high
	more or less low	high	high
	more or less high	high	high
	high	high	high
	very high	high	very high
Competitive Edge	high	very low	very high
	high	low	very high
	high	more or less low	very high
	high	more or less high	very high
	high	high	very high
	high	very high	high

Table 16 (cont.): Sensitivity Results for Alternative 2. (Depicting changes with respect to linguistic attributes from the strategic module)

Attribute	Rating	Weight	Strategic Viability
Competitive Edge	very low	very high	more or less high
	low	very high	more or less high
	more or less low	very high	high
	more or less high	very high	high
	high	very high	very high
	very high	very high	very high

5.4.1 Results from the Economic Module

The results from the economic analysis show that the first alternative has a payback period of 4 years and a net present worth in the range of \$ 27,465.23 and \$ 81,274.19, but with some possibility of falling to \$ -6,450.79 or rising to \$ 83,850.14. The crisp payback period of 4 years looks very promising, as does the NPV. The possibility of the NPV falling below zero can be considered almost insignificant. This is evident from the fact that the lower bound for the most possible range of values, i.e. \$ 27,465.23, in absolute terms is almost four times the maximum negative value attainable, i.e. \$ -6,450.79. Consequently, the first alternative looks to be very promising economically.

The second alternative has a payback period of 4 - 5 years, and a net present worth in the range of \$ 356.08 and \$ 74,656.90. There is some possibility of it falling to \$ -35,887.48 or rising to \$ 75,599.70. The one year variation in the payback can be considered insignificant, especially since a payback period of either four or five years can be considered promising. However, the lower bound for the most possible range of values, i.e. \$ 356.08, is not only very close to zero, in absolute terms it is almost 1/100th the most negative value that can be attained, i.e. \$ -35,887.48. The second alternative therefore, definitely does not rate very favorably on NPV, especially when compared to the first alternative.

5.4.2 Results from the Operational Module

The first alternative has a desirability of approximately 50 on a scale of zero to 100, with very little variation on either side. Linguistically, it has a "more or less low" operational viability. As is seen from the sensitivity analysis results, this overall project viability would not be very greatly affected by changes in the input values (See Tables 11 and 13). The project viability shows a marginal sensitivity to the ratings of the attributes "setup time," and "turn-around time," and negligible sensitivity to the other attributes. In fact, for the entire range of ratings and weights possible for each attribute, the project viability does not show a drop of below 38 or "more or less low," or a rise higher than 61 or "more or less high." (The sensitivity analysis checks for variations in the project viability with respect to variations in only one parameter, such as the rating or weight of any attribute, at one time. Thus, only slight changes in the project viability show that no particular attribute is of such overwhelming importance as to control the project viability on its own.) Therefore, it can be concluded that unless the values for more than one of the attributes were changed by significant amounts, there would be very little change in the operational desirability of the project. Thus, we can say that operationally, the first alternative is only marginally desirable.

The second alternative has an operational viability of approximately 65 on a scale of zero to 100, or in linguistic terms, it has a "more or less high" desirability. From the sensitivity viewpoint, it is seen that the project viability does not change very significantly for change in the ratings or weights for the different attributes (See Tables 12 and 14). The project viability is somewhat sensitive to is the ratings for the attributes "capability to increase production," and "setup time." Consequently, the second alternative can be said to have an above-average operational viability, and in comparison with the first alternative, seems to be a better operational choice.

5.4.3 Results from the Strategic Module

The first alternative has a "more or less low" strategic desirability. The sensitivity analysis shows a reasonable degree of sensitivity towards the ratings of the attributes "flexibility for technological upgrade" and "competitive edge." The project viability ranges from "low" to "more or less high," for the entire range of values taken (See Table 15). On the other hand, the second alternative shows a "high" strategic viability. The viability is reasonably sensitive to the ratings of each of the three attributes (See Table 16). However, for the entire range of permissible values for the ratings, the viability ranges from "more or less high" to "very high." In other words, it always remains at least above average, or at least as good as the first alternative. It can be concluded therefore, that the second alternative is strategically much better than the first alternative.

5.4.4 Overall Discussion of Results

The combined results from the three modules provide a much more global perspective of the decision environment. If the two alternatives had been compared by means of traditional economic analysis techniques, the payback for the first alternative would have been four and its NPV would have been evaluated at a crisp $ 74,247.00. The payback for the second alternative would have been calculated as four, and its NPV as $ 67,644.50. Consequently, the second alternative would have been rejected in comparison with the first. Not only that, the scenario predicted would have been that both the alternatives would definitely pull the company out of trouble. The results from the model developed speak of some possibility of the promised returns not being realized. More importantly, they provide the engineering division of the company an informative base to argue their case for the second alternative when operational and strategic issues are considered with economic issues.

5.5 Analysis of the Model

Implementing the model via the hypothetical example provides a means of analyzing it, in terms of how it addresses the research problem, its success in achieving the research objectives, its weaknesses and limitations, and its strengths.

The model was found to address the research problem well, providing a means of evaluating more equitably the viability of investments in industrial projects, particularly those involving advanced manufacturing systems. It does so by providing for the consideration of not only the economic attributes of the project, but also of the other attributes that may have a significant bearing on project desirability, but which are undefinable in economic, or sometimes even numerical, terms. As seen from the results from the model, it provides a sound alternative to probability theory in accounting for uncertainty in investment analysis. In fact, it goes a step further by being able to account for the inherent imprecision present in the values for the various economic and non-economic attributes. In the operational and strategic modules, apart from providing the flexibility of linguistically defining the attribute parameters, the sensitivity analyses results provide a good overview of possible changes in project viability with changes in the various attribute values. Evidently, the model is able to achieve the objectives of this research.

However, the model is seen to have a number of limitations as well as weaknesses. These limitations and weaknesses make this model unsuitable for use in real-life situations. The first limitation is in the execution of the computer program itself. As has been indicated in the text, as well as in the user's guide in Appendix C, while entering values there are points at which a wrong value entered may lead to either faulty execution or collapse of the program. This limitation is compounded by the fact that the analyst has no means of being able to go back and rectify the erroneous values. Second, to enable simplicity in modelling, a number of important economic attributes have been left out -- for example, tax rates and depreciation. In real-life situations, such attributes are important considerations. Thus, omitting them is bound to lead to unrealistic recommendations for project desirability. Third, the analyst has, in many cases, been limited in terms of assigning values to attributes, by either specifying a constricted range, or by curtailing the very character of the attribute. Good examples of this are deterministic initial investment and project life, a ceiling of 100% variation, when specifying the levels of confidence, and having to model the ratings and weights for any attribute either linguistically or numerically, but not being able to combine both methods. Fourth, the sensitivity analyses only provide good indications of how project viabilities would change with changes in the input values. They do not account for a simultaneous change in the values of two or more attributes which, in fact, is very possible.

In spite of these limitations and weaknesses, however, the model can be considered a good prototype for the further development of investment analysis models. It compares very well against some of the other models developed that have been cited in the literature review. For example, in comparing the model with Yager's conceptual model [51], it is seen that the primary weakness of his model, that of not being able to account for numerical and linguistic values simultaneously, does not exist for this model. Also, the model developed is conceptually simpler than Jain's model [28]. A comparison with commercial software packages listed in Chapter 2 would not be entirely fair since they would obviously be more comprehensive and user friendly. However, if they were to be compared with the potential the model developed has, it would show the model off very favorably.

5.6 Summary

The hypothetical example helps demonstrate the ability of the model to achieve the objectives of this research. As the results show, the model provides a means of being able to account for the imprecision and uncertainty that prevails in today's investment decision environment. It provides a more informed perspective of the alternative being analyzed. In doing so, it also allows for the use of both linguistic and numerical quantifiers. Overall, it demonstrates the successful application of fuzzy set theory to investment analysis, especially in the field of high-technology.

At the same time, an analysis of the model, based in part on the results of the hypothetical example, reveals some of the limitations and weak points of the model. From the economic viewpoint, it is clear that the model does not account for a sufficiently comprehensive set of parameters, thereby making the results unrealistic to a certain extent. From the viewpoint of the operational and strategic models, it is also seen to be very simplistic and in need of some enhancement before it can be used in real-world situations. Based on the limitations, some suggestions for further research in this area are presented in Chapter 6.

6. Conclusions and Recommendations

6.1 Conclusions

The model developed as part of this research provides a means of analyzing investments especially for high technology, using fuzzy set theory. It provides an alternative to probability theory for the modelling of uncertainty, and additionally, is able to handle imprecision. It also provides the ability to look at projects from a more informed perspective, by "forcing" the consideration of tangible and intangible non-economic attributes, along with economic attributes. In the consideration of these non-economic attributes, it attempts to bridge the gap between the purely numerical logic of a computer and the more complex logic of the human thought process by allowing inputs in linguistic as well as numerical form. Thus, rather than mentally convert a phrase like "very important" into a crisp number, the analyst is able to enter it in terms that are more analogous to the linguistic phrase itself. The model has a definite structure that, it is hoped, will be able to help in the identification and classification of attributes into the three main categories identified. It returns five values, all of which, when compared one to one with corresponding values for different alternatives, aid the analyst in comparing equitably, the merits and demerits of each alternative with respect to others.

The model is admittedly simplistic, yet it satisfies the objectives of the research and the results are very promising. The model is a sound starting point for the development of more complex and more significant decision support systems. There are many avenues for furthering the scope of this model or to develop newer, more sophisticated models. Some recommendations for future research and development are discussed in the following section.

6.2 Recommendations for Further Research

As has been discussed above, the model developed serves to overcome many of the limitations present in investment analysis today. However, it is only one step in the right direction, but one that opens up many promising possibilities for further research. These are outlined below, roughly in the order of increasing complexity:

6.2.1 Enhancement of the Computer Model

In context of the computer program, the model can be made more sophisticated. Due to its highly interactive yet simplistic nature, the model is not able to account for incorrect or questionable values entered at many places. To be able to do that , the programming effort would have been increased significantly. So, keeping in mind the research objective of building a basic model to demonstrate the utility of fuzzy set theory in modelling the investment decision, the ability of the model to handle such errors was restricted. However, the computer program has been developed in such a way as to allow easy incorporation of such enhancements. Another enhancement to the program may be the use of computer graphics to depict results.

6.2.2 Further Development of the Economic Module

As is evident from the results, the model has an inherent capability to be able to handle imprecision and uncertainty. However, the need for simplification dictated that many important parameters that are used in realistic situations, such as taxes, depreciation, etc., be omitted from consideration. The model also does not consider the imprecision of other factors such as initial investment, the life of the project, or the duration of uniform flows for similar reasons. The mathematical complexity of the model would increase tremendously by the inclusion of such parameters, but it would serve to enhance the significance of the model greatly. Additionally, variations in parameters, such as tax rates, are frequently one of the major causes of traditional economic analyses providing incorrect recommendations. Fuzzy set theory would be able to model these variations and account for them in the final analyses, thereby providing for more accurate projections of project viability.

6.2.3 Further Development of the Operational and Strategic Modules

The operational and strategic modules provide good indications of the desirability of the project with respect to the non-economic, short-term, and long-term benefits. However, there are many aspects of these modules that can be developed further. These aspects are discussed below:

<u>User Defined Linguistic Scales:</u> Although the model allows the analyst a natural means of expressing the rating and weight of the given attributes, it places the limitation of having to choose a linguistic quantifier from a predetermined scale. The model can be enhanced to accept linguistic scales that are defined by the analyst. This will greatly increase the flexibility of both the modules

and serve to further close the gap between the human thought process and computer logic.

Help List of Attributes: The ability to provide the analyst a list of possible attributes to consider would be a useful addition to the current model. The list may be drawn from a data base maintained by storing attributes from previous runs of the model.

Multiple Analysts: The model currently returns values that are based on the subjective judgment of a single analyst. Thus, the results obtained from the model for the same project may vary considerably from analyst to analyst. Therefore the model could be developed to pool the judgment of more than one analyst into the final recommendations. This may provide more robust output values.

6.2.4 Overall Development in the Model

Future research should also consider a more complex development of the overall structure of the model. Some suggestions are presented below:

Multi-Stage Decision Making: The present model is limited to single-stage decision making only. Frequently however, decisions require various stages of consideration for the different attributes. The model could be enhanced to be able to handle multi-stage decision making. The effort would be greatly aided by the significant amount of literature available in the area of multi-stage decision making using fuzzy sets. The multi-stage model may be structured, so that at the second or higher stages, the project desirabilities from the three modules are considered in combination, and a single measure of merit is obtained. This measure of merit can then be used, in conjunction with the dominance principles within the fuzzy set theory, to rank the alternatives.

Knowledge-Based DSS: An ambitious yet very significant direction for future research may be the development of a knowledge-based decision support system from the current model. The investment analysis process is an extremely complex process, requiring considerable expertise. This expertise is available in human analysts, but not necessarily in every company or specific plant location. If this expertise was available in a structured, easily accessible form, it would benefit the companies greatly. Additionally, the work of one expert could be greatly aided by judgments of other experts for the same situation. A means for doing this is the knowledge-based system, which maintains a knowledge database of facts and heuristics. This database would then be accessed by another part of the system, the inference engine, which is an algorithm containing lines of reasoning and search methods, to derive logical conclusions.

There are many variations in the characteristics of knowledge-based systems, depending on the application. However, according to Canada and Sullivan [8], there are some features that are common to expert systems in general, that serve to distinguish them from conventional computer programs. These features are:

1. Separation of expert knowledge from the reasoning mechanism.
2. Complete representation of domain specific knowledge.
3. General purpose reasoning mechanism (inference engine) to use domain-specific knowledge and gathered facts to arrive at a conclusion.
4. Ability to explain and justify conclusions.
5. Ability to handle unreliable, incomplete, and uncertain data.
6. Easy-to-use natural-language human interface.

7. Modularity of represented knowledge to support rapid prototyping and refinements.

The question is whether the model developed is capable of being a starting point for the development of such a system. In fact, the model does provide a preliminary basis for evolving a knowledge-based DSS. It already has the capability of handling unreliable and incomplete data and ways to increase this capability have been discussed. Fuzzy set theory, albeit at much higher levels of mathematical complexity, has shown promise for developing natural language interfaces from its linguistic capabilities. The concept of modularity has already been initiated by the development of the three distinct modules to evaluate the alternatives. The concept of a data base attached to the model to aid the user in selecting attributes has been discussed as well. Therefore, it is seen that most of the generic qualities of knowledge-based systems are already present in the model. What is required over and above all these developments are the first three characteristics listed above, namely the development of a domain specific knowledge base and a separate reasoning mechanism or the inference engine. The ability to explain and justify conclusions automatically could also then be incorporated easily. The development of a knowledge-based DSS would enable the extraction of a lot of the information that fuzzy numbers carry and which is partially lost in models such as the one developed. In fact, it is entirely possible that the DSS would then be able to use more complex and meaningful fuzzy sets than fuzzy numbers in model development and analysis. It can thus be considered as an extremely promising research field.

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Appendix A: Definitions and Proofs

A.1 Definitions

The following definitions are applicable to the terms used in this thesis:

ALTERNATIVE

An industrial proposal or project involving an investment in new technology, that is in consideration by the management of the firm.

ATTRIBUTE

A characteristic, quality or performance parameter of the alternatives.

CONFIDENCE LEVEL

A level of surity expressed by the analyst, in the values specified for certain variables in the economic and operational modules.

FUZZY

A term meaning vague, inconclusive, indefinite, or lacking in clarity and definition.

FUZZY NUMBER

A fuzzy number is a convex and normal fuzzy subset. A fuzzy number M^* has a membership function defined by

$$\mu(x \mid M^*) = (m_1, f_1(y \mid M^*)/m_1, m_3/f_2(y \mid M^*), m_4)$$

where $m_1 < m_2 \leq m_3 < m_4 <$, $f_1(y \mid M^*)$ is a continuous monotone increasing function of y for $0 \leq y \leq 1$ with $f_1(0 \mid M^*) = m_1$ and $f_1(1 \mid M^*) = m_2$, and $f_2(y \mid M^*)$ is a continuous monotone decreasing function of y for $0 \leq y \leq 1$ with $f_2(0|M^*) = m_4$ and $f_2(1|M^*) = m_3$.

FUZZY SET

Let X be a classical set of objects, called the universe, whose generic elements are denoted x. Membership in a classical subset of A of X can be viewed as a characteristic function μ_A from X to {0, 1} such that

$$\mu_A(x) = \begin{cases} 1 \text{ iff } x \in A \\ 0 \text{ iff } x \notin A \end{cases}$$

The set {0, 1} is called a valuation set. If the valuation set is allowed to be the real interval [0, 1], A is called a fuzzy set. $\mu_A(x)$ is the grade of membership of x in A. The closer the value of $\mu_A(x)$ is to 1, the more x belongs to A. Thus, fuzzy set has no sharp boundary.

IMPRECISE

A term meaning not exact, vague, of indefinite form, nature or outline.

LINGUISTIC ATTRIBUTES

Attributes whose value, or rating is defined in terms of linguistic terms like "high," "important," or "very low," rather than in numerical terms.

MEASURES OF MERIT

Measures of merit are indices, or a common basis, for the comparison of the economic desirability of competing alternatives

NORMAL FUZZY SUBSET

A fuzzy set A is said to be normal if

$$hgt(\mu_A(x)) = 1$$

where hgt(.) or height, is the supremum of $\mu_A(x)$ over X, where X is the real number universe. This ensures that at least one real number is totally in the set.

NUMERICAL ATTRIBUTES

Attributes whose value, or rating is defined by numbers on a specified number scale, e.g. 45 on a scale of zero to 100.

UNCERTAINTY

Uncertainty stresses a lack of certitude ranging from a small falling short of definite knowledge to an almost complete lack of it, or even any conviction, especially about an outcome or result.

A.2 Proofs

Theorem 1: (a) If S^* is negative, then $PV_1(S^*, n)$ exists. Otherwise $PV_1(S^*, n)$ may not exist. (b) If S^* is positive, then $PV_2(S^*, n)$ exists. Otherwise, $PV_2(S^*, n)$ may not exist.

Proof: (a) Suppose S^* is negative. Then

$$-f_1(y|S^*)(1+f_1(y|r^*))^{-n}$$

is a decreasing function of y because $f_1(y|r^*)$ is increasing and $-f_1(y|S^*)$ is decreasing. Therefore the negative of this expression which equals $f_1(y|P^*)$ is increasing. Similarly, we note that $f_2(y|P^*)$ is a decreasing function of y. Since $s_1 < s_2 \leq s_3 < s_4 \leq 0$ and $0 < (1+r_4)^{-n} \leq (1+r_3)^{-n} < (1+r_2)^{-n} < (1+r_1)^{-n}$. It follows that $p_1 < p_2 \leq p_3 < p_4 \leq 0$.

A simple example shows that $PV_1(S_*, n)$ may be undefined when S^* is positive. Let S^* = (190, 200, 200, 210), $r^* = (0.09, 0.10, 0.10, 0.11)$, and $n = 10$. Then $p_2 = 77.1 < 80.3 = p_1$ and $f_1(y|P^*)$ is decreasing, $p_4 = 73.96 < 77.1 = p_3$ and $f_2(y|P^*)$ is increasing. Therefore, $PV_1(S^*,10)$ is not defined. (Here, the numbers are simply calculated by means of the engineering economy formulae. Thus, p_1 is simply $190 * (1 + 0.09)^{-10}$)

(b) Assume S^* is positive. Then $f_1(y|P^*)$ is increasing because $f_1(y|S^*)$ is increasing and $f_2(y|r^*)$ is decreasing. Similarly we see that $f_2(y|P^*)$ is a decreasing function of y. Since $0 < s_1 < s_2 \leq s_3 < s_4$ and $0 < (1+r_4)^{-n} < (1+r_3)^{-n} \leq (1+r_2)^{-n} < (1+r_1)^{-n}$ it follows that $0 < p_1 < p_2 \leq p_3 < p_4$.

Let $S^* = (-210, -200, -200, -190)$, $r^* = (0.09, 0.10, 0.10, 0.11)$, and $n = 10$. Then $p_2 = -77.1 < -73.96 = p_1$ and $f_1(y|P^*)$ is decreasing, $p_4 = -80.26 < -77.1 = p_3$ and $f_2(y|P^*)$ is increasing. Therefore $PV_2(S^*,10)$ is undefined.

Appendix B: The Computer Code

This appendix contains the entire computer code written in C. The model was divided into three files, the first containing the main model "driver" and functions that are used by all three modules, the second containing the code for the economic module and the other functions associated with it, and the third containing the code for the operational and strategic modules and the associated functions. The code is presented here in the same format.

B.1 Computer Code from File # 1

```
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include <dos.h>
#include <sys\types.h>
#include <sys\timeb.h>
#include <time.h>

struct timeb xtime;

long time1, time2;
long intval;
long intvl = 500;
long intvl1 = 1000;

void output();
void go_xy(), box(), cls();
void confid();
void choices();
```

```
main()

   {
   char econagain, operagain, stratagain;
   int out;

   go_xy(12, 35);
   printf("PLEASE WAIT\n");
   cls();

   do
     {
     cls();
     go_xy(12, 25);
     printf("ACTIVATING ECONOMIC MODULE");
     initime(intvl);
     while (!timeout());
     econmod();
     output(&out);
     if (out == 1)
        {
        system("cls");
        system("print result1");
        }
     else
        {
        system("cls");
        system("type result1 | more");
        system("pause");
        }
     cls();
     box(1, 1, 24, 79);
     box(10, 12, 16, 70);
     go_xy(13, 15);
     printf("Would you like to run the ECONOMIC MODULE again ? :");
     while (getchar() != '\n');
     scanf("%c", &econagain);
     }
   while (econagain != 'n');

   do
     {
     cls();
     go_xy(12, 25);
     printf("ACTIVATING OPERATIONAL MODULE");
     initime(intvl);
     while (!timeout());
     opermod();
     output(&out);
```

```
 if (out == 1)
    {
    system("cls");
    system("print result2");
    }
 else
    {
    system("cls");
    system("type result2 | more");
    system("pause");
    }
 cls();
 box(1, 1, 24, 79);
 box(8, 12, 16, 72);
 go_xy(11, 15);
 printf("Would you like to run the OPERATIONAL MODULE again ? :");
 while (getchar() != '\n');
 scanf("%c", &operagain);
 }
while (operagain != 'n');

do
 {
 cls();
 go_xy(12, 25);
 printf("ACTIVATING STRATEGIC MODULE");
 initime(intvl);
 while (!timeout());
 stratmod();
 output(&out);
 if (out == 1)
    {
    system("cls");
    system("print result3");
    }
 else
    {
    system("cls");
    system("type result3 | more");
    system("pause");
    }
 cls();
 box(1, 1, 24, 79);
 box(8, 12, 16, 72);
 go_xy(11, 15);
 printf("Would you like to run the STRATEGIC MODULE again ? :");
 while (getchar() != '\n');
 scanf("%c", &stratagain);
 }
```

```
    while (stratagain != 'n');
    cls();
    box(10, 20, 15, 60);
    go_xy(12, 24);
    printf("Program Terminated - Thank you !");
    }



 initime(hsecs)

    long hsecs;
    {
    intval = (hsecs < 12) ? 12 : hsecs;
    ftime(&xtime);
    time1= (long)xtime.millitm/10 + xtime.time*100;
    }



 timeout()

    {
    ftime(&xtime);
    time2 = (long)xtime.millitm/10 + xtime.time*100;
    return( (time2-time1>intval) ? 1: 0);
    }

void output(out)

    int *out;
    {
    cls();
    box(1, 1, 24, 79);
    box(8, 10, 18, 70);
    go_xy(10, 14);
    printf("Given the following two choices :");
    go_xy(12, 25);
    printf("1.   Printing results on printer");
    go_xy(14, 25);
    printf("2.   Printing results on screen");
    go_xy(16, 14);
    printf("Please enter number corresponding to your choice :");
    scanf("%d", out);
    }

void box(stx, sty, endx, endy)

    int stx, sty, endx, endy;
```

```
{
int i;
go_xy(stx, sty);
for (i = stx+1; i<endx; i++)
  {
  go_xy(i, sty);
  putchar(177);
  go_xy(i, endy);
  putchar(177);
  }
for (i = sty+1; i<endy; i++)
  {
  go_xy(stx, i);
  putchar(177);
  go_xy(endx, i);
  putchar(177);
  }
go_xy(stx, sty);
putchar(177);
go_xy(stx, endy);
putchar(177);
go_xy(endx, sty);
putchar(177);
go_xy(endx, endy);
putchar(177);
}


void go_xy(x, y)

  int x, y;
  {
  union REGS r;
  r.h.ah = 2;
  r.h.dl = y;
  r.h.dh = x;
  r.h.bh = 0;
  int86(0x10, &r, &r);
  }


void cls()

  {
  union REGS r;
  r.h.ah = 6;
  r.h.al = 0;
```

```
r.h.ch = 0;
r.h.cl = 0;
r.h.dh = 24;
r.h.dl = 79;
r.h.bh = 7;
int86(0x10, &r, &r);
}
```

```
void confid(base, uv, lv, fuz, fuznum)

  float fuz, base, uv, lv, *fuznum;
  {
  char ans;
  float cop;
  box(10, 10, 17, 70);
  go_xy(12, 14);
  printf("Can your level of confidence be interpreted as a");
  go_xy(13, 14);
  printf("%.2f%% error in the variation you entered ? (y/n) :", fuz);
  while (getchar() != '\n');
  scanf("%c", &ans);
  if (ans == 'n')
       {
       go_xy(15, 14);
       printf("Please enter new error level (%%) :");
       scanf("%f", &cop);
       fuz = cop;
       }
  fuznum[0] = base * (1 - ((1 + fuz/100)*(lv/100)));
  fuznum[3] = base * (1 + ((1 + fuz/100)*(uv/100)));
  }
```

```
void choices(co)

  int *co;

  {
  box(11, 8, 20, 72);
  go_xy(12, 11);
  printf("Given the following choices:");
  go_xy(14, 18);
  printf("1. Very High            2. High");
  go_xy(15, 18);
  printf("3. More or Less High    4. More or Less Low");
  go_xy(16, 18);
```

```
printf("5. Low                  6. Very Low");
go_xy(18, 11);
printf("Please enter a level of confidence in the values above :");
scanf("%d", co);
}
```

B.2 Computer Code from File # 2

```
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include <dos.h>

struct cash {
            int year;
            float amount[4];
            };


econmod()

  {
  struct cash byear[20];
  float fuin[4], bi;
  float fupw[4], fuuf[4], fucf[4], fusa[4];
  float ininv, sal;
  int i1, i2, i3, i4, i5, i6, yr, life, dur;
  int futp[4], fupb[4], tm;
  char uni1, uni2, sin1, sin2;

  for (i1 = 0; i1 < 10; i1++)
    {
    for (i2 = 0; i2 < 4; i2++)
      {
      fupw[i2] = 0.0;
      fupb[i2] = 0;
      byear[i1].amount[i2] = 0;
      byear[i1].year = i1+1;
      }
    }
  cls();
  box(1, 1, 24, 79);
```

```
go_xy(23, 30);
printf(" THE ECONOMIC MODULE ");
box(9, 7, 15, 73);
go_xy(12, 10);
printf("Please enter the initial investment amount ($) :");
scanf("%f", &ininv);
fupw[0] = -ininv;
fupw[1] = -ininv;
fupw[2] = -ininv;
fupw[3] = -ininv;

cls();
box(1, 1, 24, 79);
go_xy(23, 30);
printf(" THE ECONOMIC MODULE ");
box(9, 13, 15, 67);
go_xy(12, 17);
printf("Please enter the base interest rate (%%) :");
scanf("%f", &bi);
interest(bi, fuin);
do
    {
    cls();
    box(1, 1, 24, 79);
    go_xy(23, 30);
    printf(" THE ECONOMIC MODULE ");
    box(9, 7, 15, 73);
    go_xy(12, 10);
    printf("Please enter the project life in consideration (years) :");
    scanf("%d", &life);
    }
while (life < 0 || life >= 30);

cls();
box(1, 1, 24, 79);
go_xy(23, 30);
printf(" THE ECONOMIC MODULE ");
box(9, 10, 15, 70);
go_xy(12, 14);
printf("Please enter the expected salvage value ($) :");
scanf("%f", &sal);
if (sal > 0)
    {
    salvage(sal, &byear[life-1], fusa);
    for (i3 = 0; i3 < 4; i3++)
       {
       futp[i3] = life;
       }
    present_worth(fupw, fuin, fusa, futp);
```

```
    }

cls();
box(1, 1, 24, 79);
go_xy(23, 30);
printf(" THE ECONOMIC MODULE ");
box(9, 5, 15, 75);
go_xy(12, 9);
printf("Are there any uniform cash flows to be considered ? (y/n) :");
while (getchar() != '\n');
scanf("%c", &uni1);
uni2 = 'y';
if (uni1 == 'y')
    {
    while (uni2 != 'n')
      {
      get_un_cashflo(fuuf, byear, futp, life, &dur);
      for (i4 = 1; i4 <= dur; i4++)
         {
         present_worth(fupw, fuin, fuuf, futp);
         for (i5 = 0; i5 < 4; i5++)
            {
            futp[i5] += 1;
            }
         if (futp[3] > life)
           futp[3] = life;
         }
    cls();
    box(1, 1, 24, 79);
    go_xy(23, 30);
    printf(" THE ECONOMIC MODULE ");
    box(9, 10, 15, 70);
    go_xy(12, 13);
    printf("Are there any more uniform cash flows ? (y/n) :");
    while (getchar() != '\n');
    scanf("%c", &uni2);
    }
  }

cls();
box(1, 1, 24, 79);
go_xy(23, 30);
printf(" THE ECONOMIC MODULE ");
box(10, 5, 16, 75);
go_xy(12, 9);
printf("Are there any single cash flows to be considered ? (y/n) :");
while (getchar() != '\n');
scanf("%c", &sin1);
sin2 = 'y';
```

```
  if (sin1 == 'y')
      {
      while (sin2 != 'n')
        {
        get_si_cashflo(fucf, byear, futp, life);
        present_worth(fupw, fuin, fucf, futp);
        cls();
        box(1, 1, 24, 79);
        go_xy(23, 30);
        printf(" THE ECONOMIC MODULE ");
        box(10, 5, 16, 75);
        go_xy(12, 9);
        printf("Are there any more single cash flows to consider? (y/n) :");
        while (getchar() != '\n');
        scanf("%c", &sin2);
        }
      }
  payback(fupb, ininv, byear, life);
  cls();
  econ_results(fupb, fupw, fuin, ininv, life, fusa, byear);
  }



interest(base, fuin)

  float *fuin;
  float base;
  {
  int co;
  float uv, lv;
  do
     {
     cls();
     box(1, 1, 24, 79);
     go_xy(23, 30);
     printf(" THE ECONOMIC MODULE ");
     box(7, 10, 16, 68);
     go_xy(9, 31);
     printf("INTEREST : %0.2f%%", base);
     go_xy(12, 14);
     printf("Please enter any possible lower variation (%%) :");
     while (getchar() != '\n');
     scanf("%f", &lv);
     go_xy(14, 14);
     printf("Please enter any possible upper variation (%%) :");
     while (getchar() != '\n');
     scanf("%f", &uv);
     }
```

```
   while (uv < 0 || lv < 0 || uv >= 50 || lv >= 50);
   cls();
   box(1, 1, 24, 79);
   go_xy(23, 30);
   printf(" THE ECONOMIC MODULE ");
   box(4, 1, 8, 79);
   go_xy(6, 7);
   printf("BASE INTEREST = %4.2f%%  UPPER VAR = %4.2f%%  LOWER VAR =
           %4.2f%%" ,base, uv, lv);
   choices(&co);
   fuin[1] = base * (1 - (lv/100));
   fuin[2] = base * (1 + (uv/100));
   cls();
   box(1, 1, 24, 79);
   go_xy(23, 30);
   printf(" THE ECONOMIC MODULE ");
   if (co >= 1 && co <= 6)
       {
       if (co == 1)
          confid(base, uv, lv, 0.0, fuin);
       else if (co == 2)
          confid(base, uv, lv, 20.0, fuin);
       else if (co == 3)
          confid(base, uv, lv, 40.0, fuin);
       else if (co == 4)
          confid(base, uv, lv, 60.0, fuin);
       else if (co == 5)
          confid(base, uv, lv, 80.0, fuin);
       else if (co == 6)
          confid(base, uv, lv, 100.0, fuin);
       }
   }


salvage(amount, ptr, fusa)

   float amount;
   struct cash *ptr;
   float *fusa;
   {
   int co, i1;
   float uv, lv;

   do
      {
      cls();
      box(1, 1, 24, 79);
      go_xy(23, 30);
```

```
        printf(" THE ECONOMIC MODULE ");
        box(7, 10, 16, 68);
        go_xy(9, 25);
        printf("SALVAGE AMOUNT : $ %-10.2f", amount);
        go_xy(12, 14);
        printf("Please enter any possible lower variation (%%) :");
        while (getchar() != '\n');
        scanf("%f", &lv);
        go_xy(14, 14);
        printf("Please enter any possible upper variation (%%) :");
        while (getchar() != '\n');
        scanf("%f", &uv);
        }
    while (uv < 0 || lv < 0 || uv >= 50 || lv >= 50);
    cls();
    box(4, 1, 8, 79);
    go_xy(6, 7);
    printf("SALVAGE  AMT  =  $  %-10.2f%%  UPPER  VAR  =  %4.2f%%  LOWER  VAR  =
            %4.2f%%", amount, uv, lv);
    choices(&co);
    fusa[1] = amount * (1 - (lv/100));
    fusa[2] = amount * (1 + (uv/100));
    cls();
    box(1, 1, 24, 79);
    go_xy(23, 30);
    printf(" THE ECONOMIC MODULE ");
    if (co >= 1 && co <= 6)
        {
        if (co == 1)
           confid(amount, uv, lv, 0.0, fusa);
        else if (co == 2)
           confid(amount, uv, lv, 20.0, fusa);
        else if (co == 3)
           confid(amount, uv, lv, 40.0, fusa);
        else if (co == 4)
           confid(amount, uv, lv, 60.0, fusa);
        else if (co == 5)
           confid(amount, uv, lv, 80.0, fusa);
        else if (co == 6)
           confid(amount, uv, lv, 100.0, fusa);
        }
    for (i1 = 0; i1 < 4; i1++)
        {
        ptr->amount[i1] += fusa[i1];
        }
    }


get_si_cashflo(fucf, ptr, futp, life)
```

```
float *fucf;
struct cash *ptr;
int *futp;
int life;
{
char ans;
int co, t1, te;
float amt;
float uv, lv;

do
    {
    cls();
    box(1, 1, 24, 79);
    go_xy(23, 30);
    printf(" THE ECONOMIC MODULE ");
    box(7, 9, 16, 71);
    go_xy(9, 12);
    printf("Please enter year for the single cash flow (1-%2d) :", life);
    while (getchar() !='\n');
    scanf("%d", &futp[1]);
    }
while (futp[1] > life);
futp[2] = futp[1];
go_xy(11, 12);
printf("Is there a possibility of imprecision ? (y/n) :");
while (getchar() != '\n');
scanf("%c", &ans);
if (ans == 'y')
      {
      go_xy(13, 12);
      printf("Please enter year for early occurrence :");
      scanf("%d", &futp[0]);
      go_xy(14, 12);
      printf("Please enter year for later occurence :");
      scanf("%d", &futp[3]);
      if (futp[3] > life)
        futp[3] = life;
      }
else
      {
      futp[0] = futp[1];
      futp[3] = futp[2];
      }

cls();
box(1, 1, 24, 79);
go_xy(23, 30);
```

```
printf(" THE ECONOMIC MODULE ");
box(9, 9, 15, 71);
go_xy(12, 12);
printf("Please enter amount for single cash flow ($) :", futp[1]);
while (getchar() != '\n');
scanf("%f", &amt);
do
     {
     cls();
     box(1, 1, 24, 79);
     go_xy(23, 30);
     printf(" THE ECONOMIC MODULE ");
     box(7, 10, 16, 68);
     go_xy(9, 28);
     printf("AMOUNT : $ %-10.2f", amt);
     go_xy(12, 14);
     printf("Please enter any possible lower variation (%%) :");
     while (getchar() != '\n');
     scanf("%f", &lv);
     go_xy(14, 14);
     printf("Please enter any possible upper variation (%%) :");
     while (getchar() != '\n');
     scanf("%f", &uv);
     }
while (uv < 0 || lv < 0 || uv >= 50 || lv >=50);
cls();
box(1, 1, 24, 79);
go_xy(23, 30);
printf(" THE ECONOMIC MODULE ");
box(4, 1, 9, 79);
go_xy(6, 36);
printf("YEAR  %d", futp[1]);
go_xy(7, 7);
printf("CASH FLOW = $ %-10.2f   UPPER VAR = %4.2f%%   LOWER VAR = \
        %4.2f%%", amt, uv, lv);
choices(&co);
fucf[1] = amt * (1 - (lv/100));
fucf[2] = amt * (1 + (uv/100));
cls();
box(1, 1, 24, 79);
go_xy(23, 30);
printf(" THE ECONOMIC MODULE ");
if (co >= 1 && co <= 6)
      {
      if (co == 1)
        confid(amt, uv, lv, 0.0, fucf);
      else if (co == 2)
        confid(amt, uv, lv, 20.0, fucf);
      else if (co == 3)
```

```
          confid(amt, uv, lv, 40.0, fucf);
        else if (co == 4)
          confid(amt, uv, lv, 60.0, fucf);
        else if (co == 5)
          confid(amt, uv, lv, 80.0, fucf);
        else if (co == 6)
          confid(amt, uv, lv, 100.0, fucf);
        }
   for (t1 = 0; t1 < 4; t1++)
         {
          (ptr+futp[1]-1)->amount[t1] += fucf[t1];
         }
   }



get_un_cashflo(fuuf, ptr, futp, life, dur)

   float *fuuf;
   struct cash *ptr;
   int *futp;
   int life, *dur;
   {
   int t1, t2, end, co;
   char ans;
   float unamt, lv, uv;

   cls();
   box(1, 1, 24, 79);
   go_xy(23, 30);
   printf(" THE ECONOMIC MODULE ");
   box(6, 8, 17, 72);
   go_xy(8, 11);
   printf("Please enter starting year for uniform cash flow  :");
   while (getchar() != '\n');
   scanf("%d", &futp[1]);
   futp[2] = futp[1];
   go_xy(10, 11);
   printf("Is there any possibility of imprecision (y/n) ?");
   while (getchar() != '\n');
   scanf("%c", &ans);
   if (ans == 'y')
        {
        go_xy(12, 11);
        printf("Please enter year it may start if earlier :");
        while (getchar() != '\n');
        scanf("%d", &futp[0]);
        go_xy(13, 11);
        printf("Please enter year it may start if later :");
```

```
      while (getchar() != '\n');
      scanf("%d", &futp[3]);
      if (futp[3] > life)
       futp[3] = life;
      }
 else
      {
      futp[0] = futp[1];
      futp[3] = futp[2];
      }
 go_xy(15, 11);
 printf("Please enter duration for uniform cash flow :");
 scanf("%d", dur);
 end = futp[1] + *dur - 1;
 if (end > life)
       end = life;
 cls();
 box(1, 1, 24, 79);
 go_xy(23, 30);
 printf(" THE ECONOMIC MODULE ");
 box(10, 9, 16, 71);
 go_xy(12, 12);
 printf("For years %d through %d", futp[1], end);
 go_xy(14, 12);
 printf("Please enter the uniform cash flow amount ($) :");
 scanf("%f", &unamt);
 do
    {
    cls();
    box(1, 1, 24, 79);
    go_xy(23, 30);
    printf(" THE ECONOMIC MODULE ");
    box(7, 10, 16, 68);
    go_xy(9, 28);
    printf("AMOUNT : $ %-10.2f", unamt);
    go_xy(12, 14);
    printf("Please enter any possible lower variation (%%) :");
    scanf("%f", &lv);
    go_xy(14, 14);
    printf("Please enter any possible upper variation (%%) :");
    scanf("%f", &uv);
    }
while (uv < 0 || lv < 0 || uv >= 50 || lv >=50);
cls();
box(1, 1, 24, 79);
go_xy(23, 30);
printf(" THE ECONOMIC MODULE ");
box(4, 1, 9, 79);
go_xy(6, 20);
```

```
    printf("FOR YEARS %d THROUGH %d", futp[1], end);
    go_xy(7, 7);
    printf("UNIFORM FLOW = $ %-10.2f  UPPER VAR = %4.2f%%  LOWER VAR = \
            %4.2f%%", unamt, uv, lv);
    choices(&co);
    fuuf[1] = unamt * (1 - (lv/100));
    fuuf[2] = unamt * (1 + (uv/100));
    cls();
    box(1, 1, 24, 79);
    go_xy(23, 30);
    printf(" THE ECONOMIC MODULE ");
    if (co >= 1 && co <= 6)
          {
          if (co == 1)
             confid(unamt, uv, lv, 0.0, fuuf);
          else if (co == 2)
             confid(unamt, uv, lv, 20.0, fuuf);
          else if (co == 3)
             confid(unamt, uv, lv, 40.0, fuuf);
          else if (co == 4)
             confid(unamt, uv, lv, 60.0, fuuf);
          else if (co == 5)
             confid(unamt, uv, lv, 80.0, fuuf);
          else if (co == 6)
             confid(unamt, uv, lv, 100.0, fuuf);
          }
    for (t1 = futp[1]; t1 <= end; t1++)
         {
         for (t2 = 0; t2 < 4; t2++)
          (ptr+t1-1)->amount[t2] += fuuf[t2];
         }
    }



present_worth(fupw, fuin, fufl, futp)

    float *fupw, *fufl, *fuin;
    int *futp;
    {
    float f0, f1, f2, f3;
    int tmp;

    f0 = pow((1 + fuin[3]/100.0), -futp[3]);
    f1 = pow((1 + fuin[2]/100.0), -futp[2]);
    f2 = pow((1 + fuin[1]/100.0), -futp[1]);
    f3 = pow((1 + fuin[0]/100.0), -futp[0]);
    if (fufl[0] >= 0 && fufl[1] >= 0 && fufl[2] >= 0 && fufl[3] >= 0)
         {
```

```
        fupw[0] += fufl[0]*f0;
        fupw[1] += fufl[1]*f1;
        fupw[2] += fufl[2]*f2;
        fupw[3] += fufl[3]*f3;
        }
    else if (fufl[0] <= 0 && fufl[1] <= 0 && fufl[2] <= 0 && fufl[3] <= 0)
        {
        fupw[0] += fufl[0]*f3;
        fupw[1] += fufl[1]*f2;
        fupw[2] += fufl[2]*f1;
        fupw[3] += fufl[3]*f0;
        }
    }


payback(fupb, ininv, ptr, year)

    int *fupb, year;
    float ininv;
    struct cash *ptr;
    {
    float pbcal[4];
    int t1, t2;

    pbcal[0] = -ininv;
    pbcal[1] = -ininv;
    pbcal[2] = -ininv;
    pbcal[3] = -ininv;
    for (t1 = 1; t1 <= year; t1++, ptr++)
       {
       for (t2 = 0; t2 < 4; t2++)
          {
          if (pbcal[t2] < 0)
           {
           pbcal[t2] += ptr->amount[t2];
           if (pbcal[t2] >= 0)
             fupb[t2] = ptr->year;
           }
          }
       }
    }


econ_results(fupb, fupw, fuin, invest, life, fusa)
```

call (Pg [illegible]) 6YEAR [illegible]

```
    float *fupw, *fuin, invest, *fusa;
    int life, *fupb;
```

```
{
FILE *ecres;

ecres = fopen("result1", "w");
fprintf(ecres, "\nRESULTS from  THE ECONOMIC MODULE \n\n");
fprintf(ecres, "\nPayback Results\n\n");
fprintf(ecres, "%d %d %d %d", fupb[3], fupb[2], fupb[1], fupb[0]);
fprintf(ecres, "\n\n\nNet Present Value Results\n\n");
fprintf(ecres, "%.2f %.2f %.2f %.2f", fupw[0], fupw[1], fupw[2], fupw[3]);
fclose(ecres);
}
```

B.3 Computer Code from File # 3

```
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include <dos.h>

struct attrib {
            char name[20];
            int ln;
            float n_w_enter;
            float n_r_enter;
            char *l_w_enter;
            char *l_r_enter;
            float weight[4];
            float rat[4];
            float wtsm[4];
            };


opermod()

  {
  FILE *resoper;
  struct attrib oper[15];
  float sum[4], totw[4], ans[4];
  int i, t, totcri, pref;

  do
    {
```

```
  cls();
  box(1, 1, 24, 79);
  go_xy(23, 28);
  printf(" THE OPERATIONAL MODULE ");
  box(8, 7, 14, 73);
  go_xy(10, 11);
  printf("Please enter the total number of attributes (max. 11) :");
  scanf("%d", &totcri);
  }
while (totcri < 2 || totcri > 11);
for (i = 1; i <= totcri; i++)
  {
  cls();
  box(1, 1, 24, 79);
  go_xy(23, 28);
  printf(" THE OPERATIONAL MODULE ");
  box(10, 5, 16, 75);
  go_xy(13, 8);
  printf("Please enter the name of Attribute %d (15 char.) :", i);
  while (getchar() != '\n');
  gets(oper[i-1].name);

  do
      {
      cls();
      box(1, 1, 24, 79);
      go_xy(23, 28);
      printf(" THE OPERATIONAL MODULE ");
      box(5, 12, 18, 65);
      go_xy(7, 27);
      printf("Attribute : \"%s\"", oper[i-1].name);
      go_xy(10, 17);
      printf("Given the option of two kinds of input :");
      go_xy(12, 17);
      printf("   1. Numerical     2. Linguistic ");
      go_xy(15, 17);
      printf("Please enter your preference (1-2) :");
      scanf("%d", &pref);
      }
  while ( pref != 1  && pref != 2);

  if (pref == 1 )
      {
      oper[i-1].ln = 1;
      o_numrtng(&oper[i-1]);
      o_numwght(&oper[i-1]);
      }
  else if (pref == 2)
      {
```

```
        oper[i-1].ln = 2;
        o_linrtng(&oper[i-1]);
        o_linwght(&oper[i-1]);
        }
    }

   resoper = fopen("result2", "w");
   calc_wght_sum(oper, totcri, sum, totw, ans);
   fprintf(resoper, "\n\nRESULTS FROM THE OPERATIONAL MODULE\n\n");
   fprintf(resoper,"\tAttributes     \tRating Assigned\tWeight Assigned\n\n\n");

   for (t = 0; t < totcri; t++)
     if (oper[t].ln == 1)
       {
       fprintf(resoper, "\n\t%15s\tabout %9.2f\tabout %9.2f\n",
               oper[t].name, oper[t].n_r_enter, oper[t].n_w_enter);
       }
     else
       {
       fprintf(resoper, "\n\t%15s\t%15s\t%15s\n", oper[t].name,
               oper[t].l_r_enter, oper[t].l_w_enter);
       }
   fprintf(resoper, "\n\n\nProject viability from operational standpoint : ");
   o_reconvert(ans, resoper);
   fprintf(resoper, "\n\n\nProject viability from operational standpoint : ");
   fprintf(resoper, "%.2f, %.2f, %.2f, %.2f\n\n",ans[0],ans[1],ans[2],ans[3]);
   o_sens_anal(oper, sum, totw, totcri, resoper);
   fclose(resoper);
   }


o_linwght(ptr)

   struct attrib *ptr;
   {
   int wt;

   cls();
   box(1, 1, 24, 79);
   go_xy(23, 28);
   printf(" THE OPERATIONAL MODULE ");
   box(4, 10, 19, 70);
   go_xy(6, 29);
   printf("Attribute : \"%s\"", ptr->name);
   go_xy(8, 13);
   printf("Given the following choices :");
   choices1();
   go_xy(17, 13);
```

```
printf("Please enter your choice for weight (1-6) :");
scanf("%d", &wt);
if (wt == 1)
    {
    ptr->l_w_enter = "very high        ";
    ptr->weight[0] = 80.0;
    ptr->weight[1] = 90.0;
    ptr->weight[2] = 90.0;
    ptr->weight[3] = 100.0;
    }
else if (wt == 2)
    {
    ptr->l_w_enter = "high             ";
    ptr->weight[0] = 65.0;
    ptr->weight[1] = 75.0;
    ptr->weight[2] = 75.0;
    ptr->weight[3] = 85.0;
    }
else if (wt == 3)
    {
    ptr->l_w_enter = "more or less high";
    ptr->weight[0] = 50.0;
    ptr->weight[1] = 60.0;
    ptr->weight[2] = 60.0;
    ptr->weight[3] = 70.0;
    }
else if (wt == 4)
    {
    ptr->l_w_enter = "more or less low ";
    ptr->weight[0] = 35.0;
    ptr->weight[1] = 45.0;
    ptr->weight[2] = 45.0;
    ptr->weight[3] = 55.0;
    }
else if (wt == 5)
    {
    ptr->l_w_enter = "low              ";
    ptr->weight[0] = 20.0;
    ptr->weight[1] = 30.0;
    ptr->weight[2] = 30.0;
    ptr->weight[3] = 40.0;
    }
else if (wt == 6)
    {
    ptr->l_w_enter = "very low         ";
    ptr->weight[0] = 5.0;
    ptr->weight[1] = 15.0;
    ptr->weight[2] = 15.0;
    ptr->weight[3] = 25.0;
```

```
      }
   }
o_linrtng(ptr)

   struct attrib *ptr;
   {
   int wt;

   cls();
   box(1, 1, 24, 79);
   go_xy(23, 28);
   printf(" THE OPERATIONAL MODULE ");
   box(4, 8, 19, 70);
   go_xy(6, 29);
   printf("Attribute : \"%s\"", ptr->name);
   go_xy(8, 11);
   printf("Given the following choices :");
   choices1();
   go_xy(17, 11);
   printf("Please enter your choice for rating (1-6) :");
   scanf("%d", &wt);
   if (wt == 1)
      {
      ptr->l_r_enter = "very high         ";
      ptr->rat[0] = 80.0;
      ptr->rat[1] = 90.0;
      ptr->rat[2] = 90.0;
      ptr->rat[3] = 100.0;
      }
   else if (wt == 2)
      {
      ptr->l_r_enter = "high              ";
      ptr->rat[0] = 65.0;
      ptr->rat[1] = 75.0;
      ptr->rat[2] = 75.0;
      ptr->rat[3] = 85.0;
      }
   else if (wt == 3)
      {
      ptr->l_r_enter = "more or less high";
      ptr->rat[0] = 50.0;
      ptr->rat[1] = 60.0;
      ptr->rat[2] = 60.0;
      ptr->rat[3] = 70.0;
      }
   else if (wt == 4)
      {
      ptr->l_r_enter = "more or less low ";
      ptr->rat[0] = 35.0;
```

```
        ptr->rat[1] = 45.0;
        ptr->rat[2] = 45.0;
        ptr->rat[3] = 55.0;
        }
    else if (wt == 5)
        {
        ptr->l_r_enter = "low              ";
        ptr->rat[0] = 20.0;
        ptr->rat[1] = 30.0;
        ptr->rat[2] = 30.0;
        ptr->rat[3] = 40.0;
        }
    else if (wt == 6)
        {
        ptr->l_r_enter = "very low         ";
        ptr->rat[0] = 5.0;
        ptr->rat[1] = 15.0;
        ptr->rat[2] = 15.0;
        ptr->rat[3] = 25.0;
        }
    }


o_numrtng(ptr)

    struct attrib *ptr;
    {
    int co;
    char ans;
    float max, min, rtns;
    float nrtng, uv, lv;

    cls();
    box(1, 1, 24, 79);
    go_xy(23, 28);
    printf(" THE OPERATIONAL MODULE ");
    box(8, 10, 19, 70);
    go_xy(10, 29);
    printf("ATTRIBUTE : \"%s\"", ptr->name);
    go_xy(12, 14);
    printf("Will you define your own scale for rating? (y/n) :");
    while (getchar() != '\n');
    scanf("%c", &ans);
    if (ans == 'y')
      {
      go_xy(14, 14);
      printf("Please enter maximum value on scale :");
      while (getchar() != '\n');
```

```
    scanf("%f", &max);
    go_xy(15, 14);
    printf("Please enter minimum value on scale :");
    scanf("%f", &min);
    go_xy(17, 14);
    printf("Please enter rating on scale (%.2f-%.2f) :", max, min);
    scanf("%f", &rtns);
    nrtng = ((rtns-min)/(max-min))*100;
    }
 else if (ans == 'n')
    {
    go_xy(15, 14);
    printf("Please enter a rating on a scale of 100 : ");
    scanf("%f", &nrtng);
    }
 ptr->n_r_enter = nrtng;
 do
   {
   cls();
   box(1, 1, 24, 79);
   go_xy(23, 28);
   printf(" THE OPERATIONAL MODULE ");
   box(8, 10, 17, 70);
   go_xy(10, 14);
   printf("RATING : %.2f for ATTRIBUTE \"%s\"", nrtng, ptr->name);
   go_xy(13, 14);
   printf("Please enter any possible lower variation (%%) :");
   scanf("%f", &lv);
   go_xy(15, 14);
   printf("Please enter any possible upper variation (%%) :");
   scanf("%f", &uv);
   }
 while (uv < 0 || lv < 0 || uv >= 50 || lv >=50);
 cls();
 box(1, 1, 24, 79);
 go_xy(23, 28);
 printf(" THE OPERATIONAL MODULE ");
 box(4, 1, 9, 79);
 go_xy(6, 29);
 printf("ATTRIBUTE \"%s\"", ptr->name);
 go_xy(7, 12);
 printf("RATING = %.2f   UPPER VAR = %5.2f%%   LOWER VAR = %5.2f%%"\
               , nrtng , uv, lv);
 choices(&co);
 cls();
 box(1, 1, 24, 79);
 go_xy(23, 28);
 printf(" THE OPERATIONAL MODULE ");
 ptr->rat[1] = nrtng * (1 - lv/100);
```

```
    ptr->rat[2] = nrtng * (1 + uv/100);
    if (co >= 1 && co <= 6)
      {
      if (co == 1)
            confid(nrtng, uv, lv, 0.0, ptr->rat);
      else if (co == 2)
            confid(nrtng, uv, lv, 20.0, ptr->rat);
      else if (co == 3)
            confid(nrtng, uv, lv, 40.0, ptr->rat);
      else if (co == 4)
            confid(nrtng, uv, lv, 60.0, ptr->rat);
      else if (co == 5)
            confid(nrtng, uv, lv, 80.0, ptr->rat);
      else if (co == 6)
            confid(nrtng, uv, lv, 100.0, ptr->rat);
      }
    }


o_numwght(ptr)

    struct attrib *ptr;
    {
    int co;
    char ans;
    float max, min, wtns;
    float nwght, uv, lv;

    cls();
    box(1, 1, 24, 79);
    go_xy(23, 28);
    printf(" THE OPERATIONAL MODULE ");
    box(8, 10, 19, 70);
    go_xy(10, 29);
    printf("ATTRIBUTE : \"%s\"", ptr->name);
    go_xy(12, 14);
    printf("Will you define your own scale for weight ? (y/n):");
    while (getchar() != '\n');
    scanf("%c", &ans);
    if (ans == 'y')
       {
       go_xy(14, 14);
       printf("Please enter maximum value on scale :");
       scanf("%f", &max);
       go_xy(15, 14);
       printf("Please enter minimum value on scale :");
       scanf("%f", &min);
       go_xy(17, 14);
```

```
    printf("Please enter weight on your scale :");
    scanf("%f", &wtns);
    nwght = ((wtns-min)/(max-min))* 100;
    }
 else if (ans == 'n')
    {
    go_xy(15, 14);
    printf("Please enter a weight on a scale of 100 : ");
    scanf("%f", &nwght);
    }
 ptr->n_w_enter  = nwght;
 do
     {
     cls();
     box(1, 1, 24, 79);
     go_xy(23, 28);
     printf(" THE OPERATIONAL MODULE ");
     box(8, 10, 17, 70);
     go_xy(10, 19);
     printf("WEIGHT : %0.2f for ATTRIBUTE \"%s\"", nwght, ptr->name);
     go_xy(13, 14);
     printf("Please enter any possible lower variation (%%) :");
     while (getchar() != '\n');
     scanf("%f", &lv);
     go_xy(15, 14);
     printf("Please enter any possible upper variation (%%) :");
     while (getchar() != '\n');
     scanf("%f", &uv);
     }
 while (uv < 0 || lv < 0 || uv >= 50 || lv >=50);
 cls();
 box(1, 1, 24, 79);
 go_xy(23, 28);
 printf(" THE OPERATIONAL MODULE ");
 box(4, 1, 8, 79);
 go_xy(6, 29);
 printf("ATTRIBUTE \"%s\"", ptr->name);
 go_xy(7, 12);
 printf("WEIGHT = %.2f   UPPER VAR = %5.2f%%   LOWER VAR = %5.2f%%"\
            , nwght , uv, lv);
 choices(&co);
 cls();
 box(1, 1, 24, 79);
 go_xy(23, 28);
 printf(" THE OPERATIONAL MODULE ");
 ptr->weight[1] = nwght * (1 - lv/100);
 ptr->weight[2] = nwght * (1 + uv/100);
 if (co >= 1 && co <= 6)
    {
```

```
      if (co == 1)
         confid(nwght, uv, lv, 0.0, ptr->weight);
       else if (co == 2)
         confid(nwght, uv, lv, 20.0, ptr->weight);
       else if (co == 3)
         confid(nwght, uv, lv, 40.0, ptr->weight);
       else if (co == 4)
         confid(nwght, uv, lv, 60.0, ptr->weight);
       else if (co == 5)
         confid(nwght, uv, lv, 80.0, ptr->weight);
       else if (co == 6)
         confid(nwght, uv, lv, 100.0, ptr->weight);
       }
  }



o_sens_anal(ptr, sum, totw, k, res)

  FILE *res;
  struct attrib *ptr;
  float *sum, *totw;
  int k;
  {
  static char *linval[6] = {"very high         ", "high              ",
                            "more or less high", "more or less low ",
                            "low              ", "very low          " };
  static char *numval[6] = {"about 100", "about 80", "about 60", "about 40",
                            "about 20", "about 0 "};
  float nr[4], nw[4], newsum[4], sensum[4], newtotw[4];
  int t1, t2, t3, t4, t5;

  for (t1 = 0; t1 < k; t1++)
     {
     fprintf(res, "\n\nATTRIBUTE : %s\n\n", (ptr+t1)->name);
     for (t2 = 0; t2 < 4; t2++)
          {
          newsum[t2] = sum[t2]-(ptr+t1)->wtsm[t2];
          newtotw[t2] = totw[t2]-(ptr+t1)->weight[t2];
          }
     fprintf(res, "\nSensitivity towards weight\n\n");
     fprintf(res, "%15s\t%17s\n\n","For Weight", "Proj. Viability");

     for (t3 = 1; t3 <= 6; t3++)
           {
           nw[0] = (15.0*t3)-10.0;
           nw[1] = 15.0*t3;
           nw[2] = 15.0*t3;
           nw[3] = 15.0*t3+10;
```

```
        sensum[0] = (newsum[0]+(ptr+t1)->rat[0]*nw[0])/(newtotw[0]+nw[0]);
        sensum[1] = (newsum[1]+(ptr+t1)->rat[1]*nw[1])/(newtotw[1]+nw[1]);
        sensum[2] = (newsum[2]+(ptr+t1)->rat[2]*nw[2])/(newtotw[2]+nw[2]);
        sensum[3] = (newsum[3]+(ptr+t1)->rat[3]*nw[3])/(newtotw[3]+nw[3]);
        if ((ptr+t1)->ln == 2)
           fprintf(res, "%15s\t", linval[6-t3]);
        else if ((ptr+t1)->ln == 1)
           fprintf(res, "%15s\t", numval[6-t3]);
        o_reconvert(sensum, res);
        }
    fprintf(res, "\nSensitivity towards rating\n\n");
    fprintf(res, "%15s\t%17s\n\n","For Rating", "Proj. Viability");

    for (t4 = 1; t4 <= 6; t4++)
        {
        nr[0] = (15.0*t4)-10.0;
        nr[1] = 15.0*t4;
        nr[2] = 15.0*t4;
        nr[3] = (15.0*t4)+10.0;
        sensum[0] = (newsum[0]+(ptr+t1)->weight[0]*nr[0])/totw[0];
        sensum[1] = (newsum[1]+(ptr+t1)->weight[1]*nr[1])/totw[1];
        sensum[2] = (newsum[2]+(ptr+t1)->weight[2]*nr[2])/totw[2];
        sensum[3] = (newsum[3]+(ptr+t1)->weight[3]*nr[3])/totw[3];
        if ((ptr+t1)->ln == 2)
           fprintf(res, "%15s\t", linval[6-t4]);
        else if ((ptr+t1)->ln == 1)
           fprintf(res, "%15s\t", numval[6-t4]);
        o_reconvert(sensum, res);
        }
    }
  }


o_reconvert(sum, results)

  FILE *results;
  float *sum;
  {
  float tri1, rect, tri2;
  float totarea, num, mean, smarea;
  char *ans;

  tri1 = (sum[1]-sum[0])/2.0;
  rect = (sum[2]-sum[1]);
  tri2 = (sum[3]-sum[2])/2.0;
  totarea = tri1 + rect + tri2;
  num = totarea/2;
```

```
    if (num < tri1)
       {
       mean = sum[1] + sqrt(2*num*(1/(sum[1]-sum[0])));
       }
    else if (num >= tri1 && num <= (tri1+rect))
       {
       mean = sum[1] + (num - tri1);
       }
    else if (num > (tri1+rect))
       {
       smarea = tri2-(num-tri1-rect);
       mean = sum[3] - sqrt(2*smarea*(1/(sum[3]-sum[2])));
       }

    if (mean > 0 && mean <= 22)
       ans = "very low";
    else if (mean > 22 && mean <= 37)
       ans = "low";
    else if (mean > 37 && mean <= 52)
       ans = "more or less low";
    else if (mean > 52 && mean <= 67)
       ans = "more or less high";
    else if (mean > 67 && mean <= 82)
       ans = "high";
    else
       ans = "very high";
    fprintf(results, "%17s\n", ans);
    }


stratmod()

    {
    FILE *resstra;
    struct attrib stra[15];
    float sum[4], totw[4], ans[4];
    int i, t, totcri, pref;

    do
        {
        cls();
        box(1, 1, 24, 79);
        go_xy(23, 30);
        printf(" THE STRATEGIC MODULE ");
        box(8, 8, 14, 72);
        go_xy(11, 11);
        printf("Please enter the total number of attributes (max. 15) :");
        scanf("%d", &totcri);
```

```
        }
    while (totcri < 2 || totcri > 15);

    for (i = 1; i <= totcri; i++)
        {
        cls();
        box(1, 1, 24, 79);
        go_xy(23, 30);
        printf(" THE STRATEGIC MODULE ");
        box(10, 5, 16, 75);
        go_xy(13, 8);
        printf("Please enter the name of Attribute %d (15 char.) :", i);
        while (getchar() != '\n');
        gets(stra[i-1].name);
        stra[i-1].ln = 2;
        s_linrtng(&stra[i-1]);
        s_linwght(&stra[i-1]);
        }
    calc_wght_sum(stra, totcri, sum, totw, ans);
    resstra = fopen("result3", "w");
    fprintf(resstra, "\n\nRESULTS FROM THE STRATEGIC MODULE\n\n");
    fprintf(resstra,"\tAttributes     \tRating Assigned\t\tWeight Assigned\n\n\n");

    for (t = 0; t < totcri; t++)
            {
            fprintf(resstra, "\n%15s\t%15s\t\t%15s\n", stra[t].name,
                    stra[t].l_r_enter, stra[t].l_w_enter);
            }

    fprintf(resstra, "\nProject viability from the strategic standpoint : ");
    s_reconvert(ans, resstra);
    s_sens_anal(stra, sum, totw, totcri, resstra);
    fclose(resstra);
    }



s_linwght(ptr)

    struct attrib *ptr;
    {
    int wt;

    cls();
    box(1, 1, 24, 79);
    go_xy(23, 30);
    printf(" THE STRATEGIC MODULE ");
    box(4, 10, 19, 70);
    go_xy(6, 29);
```

```
printf("Attribute : \"%s\"", ptr->name);
go_xy(8, 13);
printf("Given the following choices :");
choices1();
go_xy(17, 13);
printf("Please enter your choice for weight (1-6) :");
scanf("%d", &wt);
if (wt == 1)
    {
    ptr->l_w_enter = "very high        ";
    ptr->weight[0] = 75.0;
    ptr->weight[1] = 85.0;
    ptr->weight[2] = 90.0;
    ptr->weight[3] = 100.0;
    }
else if (wt == 2)
    {
    ptr->l_w_enter = "high             ";
    ptr->weight[0] = 60.0;
    ptr->weight[1] = 70.0;
    ptr->weight[2] = 75.0;
    ptr->weight[3] = 85.0;
    }
else if (wt == 3)
    {
    ptr->l_w_enter = "more or less high";
    ptr->weight[0] = 45.0;
    ptr->weight[1] = 55.0;
    ptr->weight[2] = 60.0;
    ptr->weight[3] = 70.0;
    }
else if (wt == 4)
    {
    ptr->l_w_enter = "more or less low ";
    ptr->weight[0] = 30.0;
    ptr->weight[1] = 40.0;
    ptr->weight[2] = 45.0;
    ptr->weight[3] = 55.0;
    }
else if (wt == 5)
    {
    ptr->l_w_enter = "low              ";
    ptr->weight[0] = 15.0;
    ptr->weight[1] = 25.0;
    ptr->weight[2] = 30.0;
    ptr->weight[3] = 40.0;
    }
else if (wt == 6)
    {
```

```
      ptr->l_w_enter = "very low          ";
      ptr->weight[0] = 0.0;
      ptr->weight[1] = 10.0;
      ptr->weight[2] = 15.0;
      ptr->weight[3] = 25.0;
      }
   }


s_linrtng(ptr)

   struct attrib *ptr;
   {
   int wt;

   cls();
   box(1, 1, 24, 79);
   go_xy(23, 30);
   printf(" THE STRATEGIC MODULE ");
   box(4, 8, 19, 70);
   go_xy(6, 29);
   printf("Attribute : \"%s\"", ptr->name);
   go_xy(8, 11);
   printf("Given the following choices :");
   choices1();
   go_xy(17, 11);
   printf("Please enter your choice for rating (1-6) :");
   scanf("%d", &wt);
   if (wt == 1)
      {
      ptr->l_r_enter = "very high         ";
      ptr->rat[0] = 75.0;
      ptr->rat[1] = 85.0;
      ptr->rat[2] = 90.0;
      ptr->rat[3] = 100.0;
      }
   else if (wt == 2)
      {
      ptr->l_r_enter = "high              ";
      ptr->rat[0] = 60.0;
      ptr->rat[1] = 70.0;
      ptr->rat[2] = 75.0;
      ptr->rat[3] = 85.0;
      }
   else if (wt == 3)
      {
      ptr->l_r_enter = "more or less high";
      ptr->rat[0] = 45.0;
```

```
        ptr->rat[1] = 55.0;
        ptr->rat[2] = 60.0;
        ptr->rat[3] = 70.0;
        }
    else if (wt == 4)
        {
        ptr->l_r_enter = "more or less low ";
        ptr->rat[0] = 30.0;
        ptr->rat[1] = 40.0;
        ptr->rat[2] = 45.0;
        ptr->rat[3] = 55.0;
        }
    else if (wt == 5)
        {
        ptr->l_r_enter = "low              ";
        ptr->rat[0] = 15.0;
        ptr->rat[1] = 25.0;
        ptr->rat[2] = 30.0;
        ptr->rat[3] = 40.0;
        }
    else if (wt == 6)
        {
        ptr->l_r_enter = "very low         ";
        ptr->rat[0] = 0.0;
        ptr->rat[1] = 10.0;
        ptr->rat[2] = 15.0;
        ptr->rat[3] = 25.0;
        }
    }


s_reconvert(sum, results)

    FILE *results;
    float *sum;
    {
    float tri1, rect, tri2;
    float totarea, num, mean, smarea;
    char *ans;

    tri1 = (sum[1]-sum[0])/2.0;
    rect = (sum[2]-sum[1]);
    tri2 = (sum[3]-sum[2])/2.0;
    totarea = tri1 + rect + tri2;
    num = totarea/2;

    if (num < tri1)
      {
```

```
      mean = sum[1] + sqrt(2*num*(1/(sum[1]-sum[0])));
      }
   else if (num >= tri1 && num <= (tri1+rect))
      {
      mean = sum[1] + (num - tri1);
      }
   else if (num > (tri1+rect))
      {
      smarea = tri2-(num-tri1-rect);
      mean = sum[3] - sqrt(2*smarea*(1/(sum[3]-sum[2])));
      }

   if (mean > 0 && mean <= 22)
      ans = "very low";
   else if (mean > 22 && mean <= 37)
      ans = "low";
   else if (mean > 37 && mean <= 52)
      ans = "more or less low";
   else if (mean > 52 && mean <= 67)
      ans = "more or less high";
   else if (mean > 67 && mean <= 82)
      ans = "high";
   else
      ans = "very high";
   fprintf(results, "%17s\n", ans);
   }



s_sens_anal(ptr, sum, totw, k, res)

   FILE *res;
   struct attrib *ptr;
   float *sum, *totw;
   int k;
   {
   static char *linval[6] = {"very high        ", "high             ",
                             "more or less high", "more or less low ",
                             "low              ", "very low         " };

   float nr[4], nw[4], newsum[4], sensum[4], newtotw[4];
   int t1, t2, t3, t3a, t4, t4a, t5;

   for (t1 = 0; t1 < k; t1++)
      {
      fprintf(res, "\n\nATTRIBUTE : %s\n\n", (ptr+t1)->name);

      for (t2 = 0; t2 < 4; t2++)
          {
```

```
        newsum[t2] = sum[t2]-(ptr+t1)->wtsm[t2];
        newtotw[t2] = totw[t2]-(ptr+t1)->weight[t2];
        }
    fprintf(res, "\nSensitivity towards weight\n\n");
    fprintf(res, "%15s\t%17s\n\n","For Weight", "Proj. Viability");

    for (t3 = 1; t3 <= 6; t3++)
         {
         nw[0] = (15.0*t3)-15.0;
         nw[1] = 15.0*t3;
         nw[2] = 15.0*t3;
         nw[3] = (15.0*t3)+15.0;

         for (t3a = 0; t3a < 4; t3a++)
            {
            if (nw[t3a] > 100)
              nw[t3a] = 100.0;
            }
         sensum[0] = (newsum[0]+(ptr+t1)->rat[0]*nw[0])/(nw[0]+newtotw[0]);
         sensum[1] = (newsum[1]+(ptr+t1)->rat[1]*nw[1])/(nw[1]+newtotw[1]);
         sensum[2] = (newsum[2]+(ptr+t1)->rat[2]*nw[2])/(nw[2]+newtotw[2]);
         sensum[3] = (newsum[3]+(ptr+t1)->rat[3]*nw[3])/(nw[3]+newtotw[3]);

         fprintf(res, "%15s\t", linval[6-t3]);
         s_reconvert(sensum, res);

         }
   fprintf(res, "\nSensitivity towards rating\n\n");
   fprintf(res, "%15s\t%17s\n\n","For Rating", "Proj. Viability");

   for (t4 = 1; t4 <= 6; t4++)
        {
        nr[0] = (15.0*t4)-15.0;
        nr[1] = 15.0*t4;
        nr[2] = 15.0*t4;
        nr[3] = (15.0*t4)+15.0;
        for (t4a = 0; t4a < 4; t4a++)
           {
           if (nr[t4a] > 100)
             nr[t4a] = 100.0;
           }
        sensum[0] = (newsum[0]+(ptr+t1)->weight[0]*nr[0])/totw[0];
        sensum[1] = (newsum[1]+(ptr+t1)->weight[1]*nr[1])/totw[1];
        sensum[2] = (newsum[2]+(ptr+t1)->weight[2]*nr[2])/totw[2];
        sensum[3] = (newsum[3]+(ptr+t1)->weight[3]*nr[3])/totw[3];
        fprintf(res, "%15s\t", linval[6-t4]);
        s_reconvert(sensum, res);
        }
}
```

```
   }


choices1()

   {
   go_xy(10, 18);
   printf("1. Very Important (Very High)");
   go_xy(11, 18);
   printf("2. Important (High)");
   go_xy(12, 18);
   printf("3. More or less Important (More or less High)");
   go_xy(13, 18);
   printf("4. More or less Unimportant (More or less Low)");
   go_xy(14, 18);
   printf("5. Unimportant (Low)");
   go_xy(15, 18);
   printf("6. Least Important (Very Low)");
   }


calc_wght_sum(ptr, k, sum, totw, ans)

   struct attrib *ptr;
   float *sum, *totw, *ans;
   int k;
   {
   int a, i, j;

   for (a = 0; a < 4; a++)
       {
       totw[a] = 0;
       ans[a] = 0;
       sum[a] = 0;
       }

   for (i = 1; i <= k; i++, ptr++)
     {
     totw[0] += ptr->weight[0];
     totw[1] += ptr->weight[1];
     totw[2] += ptr->weight[2];
     totw[3] += ptr->weight[3];

     ptr->wtsm[0] = ptr->rat[0]*ptr->weight[0];
     ptr->wtsm[1] = ptr->rat[1]*ptr->weight[1];
     ptr->wtsm[2] = ptr->rat[2]*ptr->weight[2];
     ptr->wtsm[3] = ptr->rat[3]*ptr->weight[3];
```

```
  sum[0] += ptr->wtsm[0];
  sum[1] += ptr->wtsm[1];
  sum[2] += ptr->wtsm[2];
  sum[3] += ptr->wtsm[3];
  }
  for (j = 0; j < 4; j++)
       {
       ans[j] = sum[j]/totw[j];
       }
}
```

Appendix C: Guide to Implementation

C.1 Introduction

This appendix contains a brief guide to implementing the computer model developed during the course of this research. Wherever necessary, the explanation is supplemented by prints of some of the screens and menus as they would appear when the model is being implemented.

C.2 What Is Needed to Start

The following minimum requirements must be met for successful implementation of the computer model :

1. An IBM PC, PC/XT, AT or a 100% compatible with at least 640K RAM on the motherboard.
2. A monochrome or color monitor.
3. A 5.25" double density floppy drive either integral to the computer or external.
4. A dot matrix printer.
5. A 5.25" diskette of DOS, version 3.0 or higher.

C.3 Starting The Model

Once the items listed above have been verified to be present, the following steps must be taken to activate the model :

1. Boot the computer up with the DOS diskette.
2. Insert floppy containing the executable code for the computer model in the floppy drive.
3. Type in "ANALYZE" and then press <return>.

In a few seconds, the first screen for the economic module should appear on the monitor. If it doesn't, there may be a problem with the computer configuration, the wrong floppy may have been inserted, or the executable code is corrupted. Please recheck configuration or floppy, or if these are found to be correct, obtain a new copy of the executable code.

C.4 Instructions for Implementing the Model

Once the model has been activated, it will activate the economic, operational and strategic modules in that order. The questions and menus that appear in the course of the running of the model are mostly self explanatory. However, to further facilitate your task of entering the values, some important points that must be borne in mind are presented below.

C.4.1 Instructions for the Economic Module

The instructions for the entering data into the economic module will be divided according to the major values needed by it. These are 1) initial investment, 2) interest rate, 3) project life, 4) salvage amount, 5) uniform cash flow values and 6) single cash flow values. The economic module handles these major values in the order shown.

Initial Investment : The initial investment requires only one number to define it completely for the model. Please note that the model is already set up internally to read investment as a negative cash flow, so you must not enter the value in negative terms. You may enter the number as a decimal or a whole number.

Interest Rate : The module requires four inputs from you to define the interest rate as a fuzzy number. It will first prompt you for a base value. This is the value that you would ordinarily use as the interest rate when using conventional economic analysis techniques. This value must be entered as a percentage value. The lower limit is 0% and the upper limit is 50%. If a value below zero is specified, it will cause the model to crash and you will have to restart the model. Values above 50 will be accepted by the model, but the percentage error in the results will be very high. Next, you will be asked to specify lower and upper variations that you may expect, with respect to the base value you specified. These values are to be entered as percentages of the base value. Thus if the base value you entered was 20%, and you entered a lower variation of 10%, the lower end of the interval would be 18%. Figure C1 shows how the screen would look for the determination of the variations. The range of values permitted is 0-50% on either side of the base value. After the variations have been specified, the module will prompt you for your level of confidence associated with your inputs. You are provided a set of six linguistic phrases from which to make your selection. The screen at this time will look as shown in Figure C2. You must input a number between 1 and 6 on this screen. Any number other than this will not be accepted, and it may cause the model running to be terminated abnormally, in which case you would have to restart

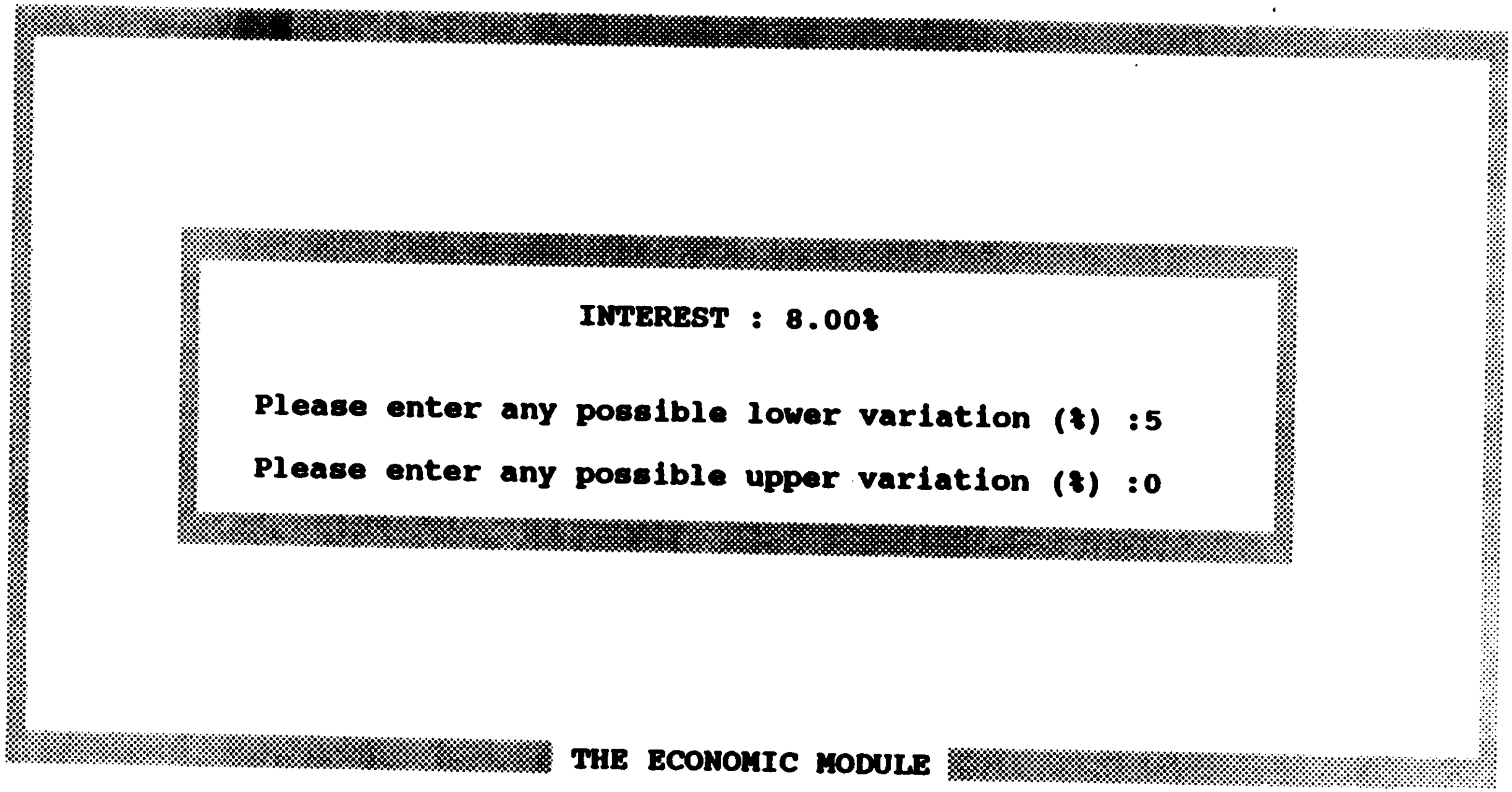

Figure C1 : Computer Screen for Inputting Variations

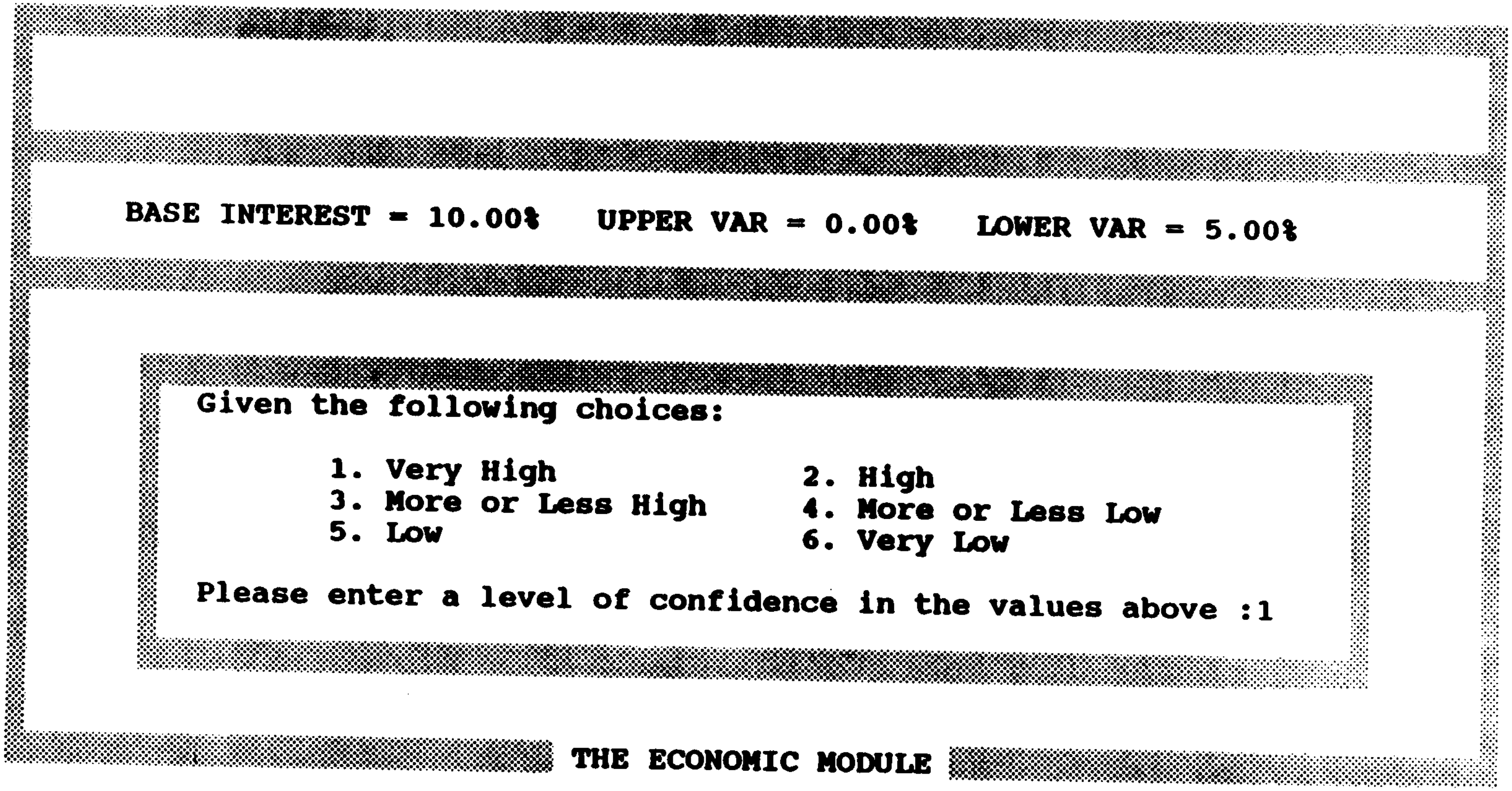

Figure C2 : Computer Screen for Inputting Level of Confidence the model. With each of the six phrases, the module associates a percentage value that specifies the variation possible in the percentage variations you defined for the base value. After you choose the linguistic phrase of your choice, the module will inform of you the percentage value it is associating with your choice. At this point, you will have the option of changing that value if you deem it necessary. The range of values allowed to you are 0-100%.

Project Life : The module requires only a single number to completely define the project life. You must enter an integer value for the project life. There is no limit imposed by the module on the project life, but it is recommended to keep the value below 30 years to keep the mathematical burden on the module low.

Salvage Amount : The module goes through the same procedure for the salvage amount as it did for the interest rate. You will be prompted for the same four inputs. Then the salvage amount will be taken automatically as the cash flow in the last year of project life.

Uniform Cash Flow Values : You are permitted to enter as many uniform cash flows as you desire. The module will prompt you to enter the year the cash flow starts. You must enter a value that lies between 1 and the project life. Then the module will ask you if you envisage any imprecision associated with the time of occurrence of the cash flow. If you answer "yes," then you will be prompted for two values, specifying the possible years in which the cash flow may start earlier or later. At this point, the module will accept any integer value you enter, since it has not been structured to account for any error values at this point. However, you must ensure that the first value entered is less than or equal to the original value specified, and the second value is more than or equal to it. Also, the difference between either of the two values and the original value must not be greater than 2. The module will then ask you for the duration of the cash flow and will apply the imprecision you specified to every year for the cash flow. If the imprecision for any year, or the duration itself is such that it causes the cash flow to spill over the project life, the imprecision or duration will be automatically be reduced in such a way as to stay within the project life. If you answer "no" for imprecision in the time of occurrence, then the module will simply ask you to enter the duration of the cash flow. As stated for imprecise times of occurrence, if the duration you enter is such that it throws the uniform cash flow across the project life, the duration will be automatically reduced so that the project life is not overstepped. After the time period for the uniform flow has been determined along with any possible imprecision values, the module will prompt you for the amount and this amount will be modelled in the same way as the interest rate. You are permitted negative as well as positive cash flow amounts. Figure C3 shows the appearance of the screen when the values related to time of occurrence of the cash flows are being input.

Single Cash Flow Values.: You are allowed an unlimited number of single cash flows and they may be negative or positive. The module will first prompt you for the year the cash flow is expected to occur. It will then ask you if there is any imprecision associated with the time of occurrence. If you answer "yes," you will be able to model it in the same way as you did for the uniform cash flow amount. The amount of the cash flow will then be asked and the same procedure for modelling will be followed as for the interest and other values, to model its imprecision, if you perceive any.

Once the main values are completely determined, the module will perform the necessary calculations, and then prompt you for your preference as to whether you want to view the results on the screen or you want a printout. It is recommended that you opt for the printout, since the module will next ask you whether you wish to run the module again, and if you answer "yes," the results from the previous run will be erased.

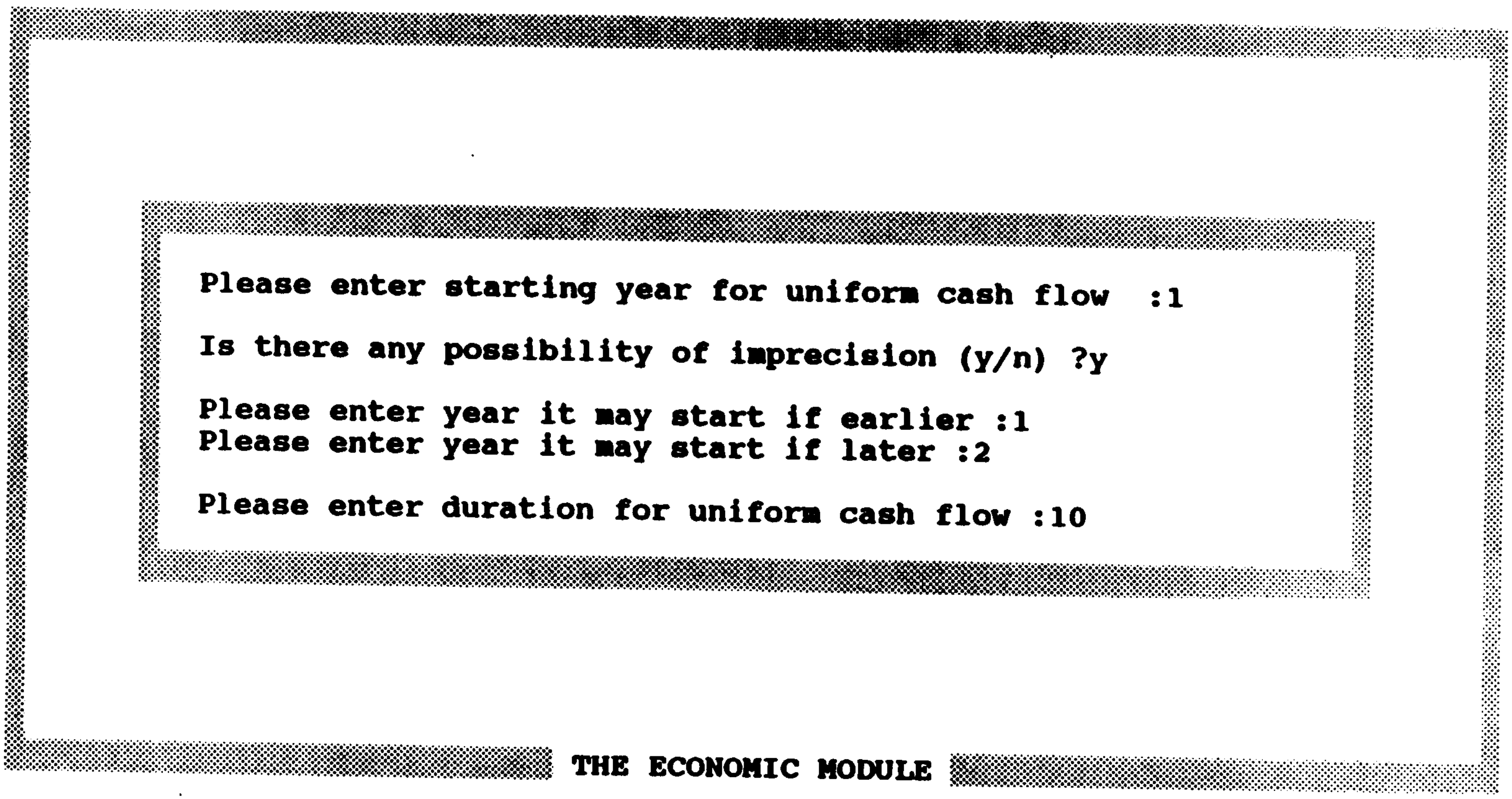

Figure C3 : Computer Screen for Inputting Imprecision in Time of Occurrence

C.4.2 Instructions for the Operational Module

The operational module will first prompt you for the total number of attributes you wish to consider. You are permitted a minimum of 2 and a maximum of 11 attributes for the operational module. Therefore at this point, you must enter a number between 2 and 15. The module will then proceed to obtain information about the attributes one by one. It will first ask you for the name of the attribute. You are limited to a maximum of 15 characters for the name of the attribute, inclusive of all spaces. Once the name has been entered, the module will ask you your preference with respect to how you wish to define the attribute values. Depending upon your preference, numerical or linguistic, the module prompts you for two entirely different sets of questions.

Defining Values for Numerical Attributes : If you choose to provide information about the attribute numerically, the module will first ask you if you would like to define your own scale for the rating. It may be noted that the rating for an attribute is a measure of how well it satisfies the final objective. If you answer "yes" to the question, the module will ask you for the highest and lowest values on the scale that you wish to specify, and then the value that you wish to assign to that particular attribute on that scale. If you answer "no," then the module will ask you for a rating on a scale of 0 to 100. Figures C4 and C5 show what the screens would look like for the two cases. The module will then prompt you for the weight of the attribute. The procedure is exactly the same as for the rating. The weight for an attribute is a measure of its importance for achieving the ultimate objective.

At this stage, the model is very susceptible to erroneous values, and it is consequently recommended that you exercise extra care in entering the values.

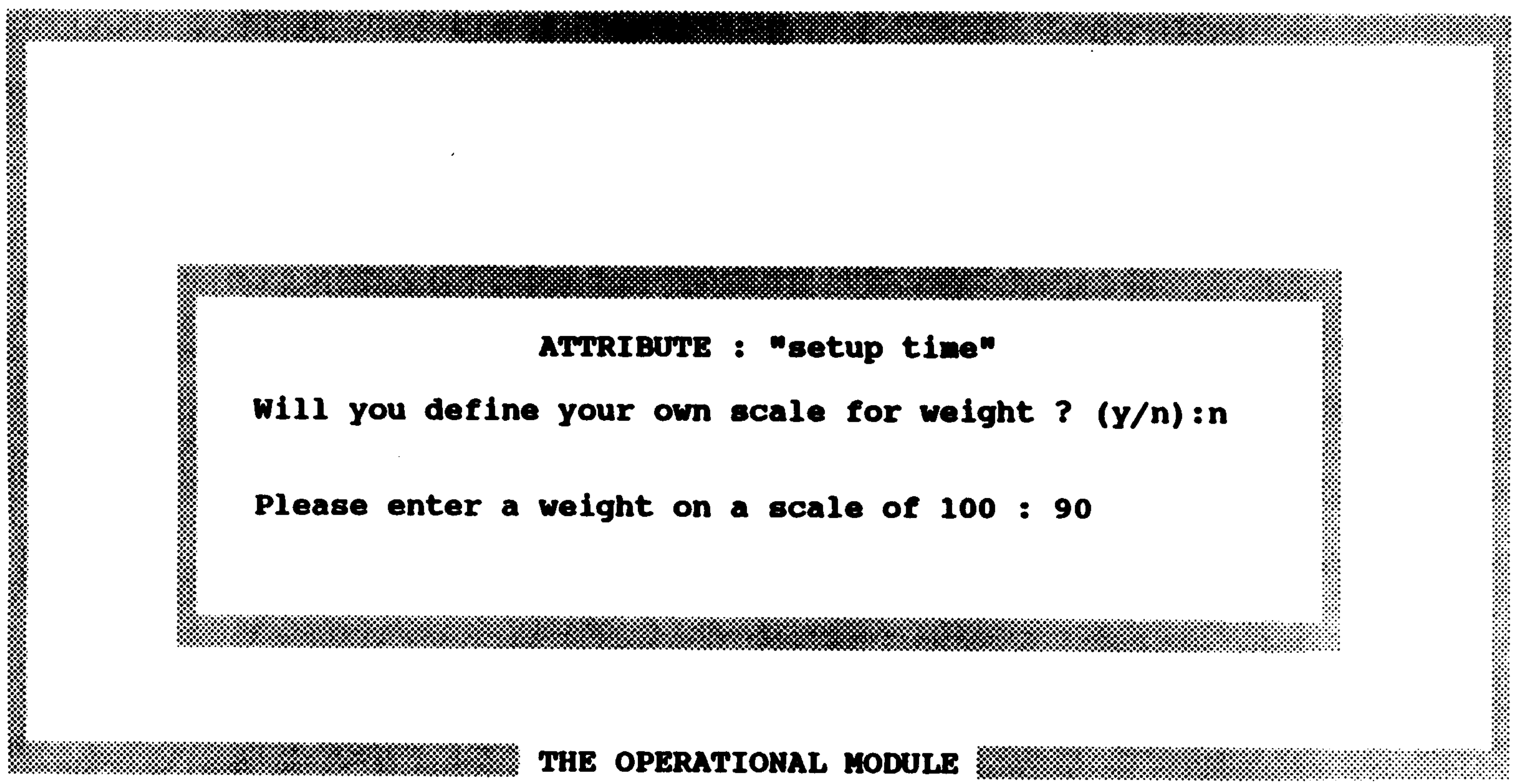

Figure C4 : Computer Screen for Inputting Values on Scale of 100

```
ATTRIBUTE : "production rate"

Will you define your own scale for rating? (y/n) :y

Please enter maximum value on scale :500000
Please enter minimum value on scale :0

Please enter rating on scale (500000.00-0.00) :150000

THE OPERATIONAL MODULE
```

Figure C5 : Computer Screen for Inputting Values on Self-Defined Scale

Defining Values for Linguistic Attributes : If you choose to input information for the attribute in linguistic rather than numerical terms, the module will display a screen, giving you a choice of six symmetrically spaced linguistic quantifiers. You may then choose which quantifier best describes your rating for the attribute. Figure C6 shows how the computer screen would look like at this time. The module will then ask you to choose from the same set of linguistic quantifiers, one that best represents the weight that you wish to attach to that attribute.

Thus, the module will progress through each of the attributes. It will then perform the necessary calculations as well as run an automatic sensitivity analysis. Having finished, it will prompt you to enter your preference for either printing the results on a printer or viewing them on a screen. It is recommended that you opt for the printout, for the reasons outlined in the instructions for the economic module.

C.4.3 Instructions for the Strategic Module

The procedure for entering information regarding the attributes is the same as the operational module except that in the strategic module, you do not have the option of entering the information in numerical terms. The module will first ask you for the total number of attributes you wish to consider. Again, you are limited to a minimum of 2 and a maximum of 11 attributes. Thereafter, the module will prompt you for the names, ratings and weights for each of the attributes. You are limited to a maximum of 15 characters for the name of the attribute, including spaces. For the rating and the weight, the same set of six quantifiers used in the operational module will be displayed for you on the screen and you will be asked for your choice of quantifier to represent the rating and the weight. It may be noted that even though the quantifiers are externally the same as

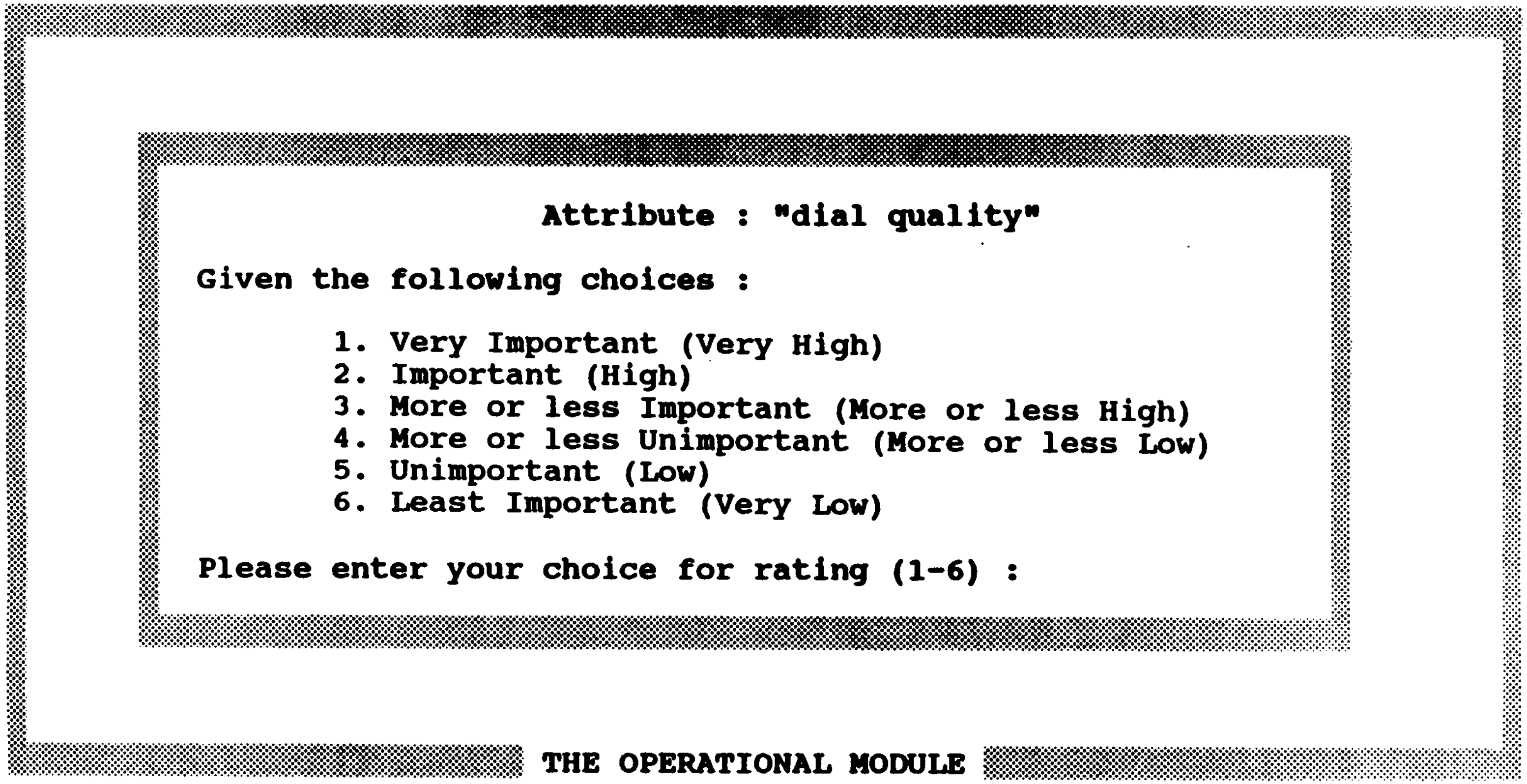

Figure C6 : Computer Screen for Inputting Linguistic Quantifiers the ones in the operational module, they have different internal representations.

After all the attributes have been defined, the module, will perform the necessary calculations and automatically run a sensitivity analysis. Then, similar to the economic and operational modules, it will ask you for your preference with respect to result output. The recommendation is the same here as it was in the previous two modules.

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