Strategic Decision Processes in Information Technology Using Fuzzy Composite Programming

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ABSTRACT: Strategic decision processes require proper construction of the decision making model and the inclusion of all relevant information and the knowledge about that information. To that end, this discussion addresses the construction of a decision making model using fuzzy composite programming (FCP). FCP is a hierarchical process which composes rudimentary elements into higher level components of the decision making model and uses fuzzy numbers to represent information and the quality of the information. The result is a comparison of alternatives and the relative agreement of those alternatives with an idealized solution. The decision model is demonstrated using a strategic decision making scenario generally common to the IT industry.

KEYWORDS: fuzzy composite programming, decision making process, information technology, outsourcing

INTRODUCTION

Appropriate corporate decision making has always been of utmost importance. Traditionally, these decisions are in the hands of a few people that are skilled in balancing corporate concerns and information. Shortcomings of this process include that communication, documentation, and defense of the decision is not structured. Also, quality improvement of the decision making process is not feasible due to lack of repeatability and viable decision making data. One method addressing these issues is to use structured decision making process. One such process is fuzzy composite programming (FCP).

FCP is a distance based multi-objective optimization problem that uses fuzzy representation of uncertainty (Bardossy and Duckstein, 1992). Examples of FCP methodology include management of a karstic aquifer (Bardossy and Duckstein, 1992), nitrate risk management (Lee et al., 1992), management of dredged material (Lee et al., 1991) and landfill hazard ranking (Hagemeister et al., 1996). In each case previously mentioned, as well as the example described in this paper, the authors use fuzzy sets to describe the inherent imprecision and ambiguity associated with the decision making variables.

The advantage of FCP is that it provides a method for resolving competing and conflicting objectives. As the decision making objectives and detailed components are listed, evaluated, and prioritized, the relevant information is documented and can be easily communicated. The 'fuzzy' part of the process allows the decision maker to prioritize objectives despite uncertainties and ambiguities associated with the components. The result is a graphical description of the performance of the decision alternatives.

LITERATURE REVIEW

Decision models and decision making tools have been developed over a number of years. Many of them are over-simplified to the point that they lack utility. Others become so complex and detailed that the focus turns from decision making to data collection. The type of decision models appropriate for this application is classified as a multi-criteria, multi-objective, competing objective, multi-attribute and a number of other descriptors. The common component is that complete agreement about the objective of the decision is not achieved. The decision maker is left to balance these competing issues.

A number of approaches have been used. Wei and Weber (1995) incorporated expert opinion to address multi-criteria decision making for waste management concerns. Lawrence et al. (1997) used a similar approach but combined measured data and expert opinion to address semiarid rangeland concerns.

Yakowitz et al. (1993) examined a technique to rank the priorities associated with the importance of contributing attributes of the decision in question. This technique allows the user to determine the influence of advocacy and the sensitivity of the overall decision to that advocacy. This techniques has been applied to environmental management (Yakowitz and Hipel, 1997), and water quality and economics (Heilman et al. 1997).

Crisp or non-fuzzy compromise programming forms the basis for composite programming and employs a single level non-normalized distance based methodology (Zeleny, 1973). Bardosy et al. (1985) developed composite programming that extended compromise programming to a normalized multilevel methodology. Composite programming has been used by Woldt and Bogardi (1992) to develop a methodology for designing a ground water monitoring network that can be used to detect and map environmental contamination. The addition of fuzzy set theory (Zadeh, 1965) to compromise programming is used to represent uncertainties of the indicators. In a manner similar to the composite programming extension, fuzzy compromise programming can be extended to a normalized multilevel distance based methodology to account for uncertainties, also known as FCP (Bardossy and Duckstein, 1992). FCP is a distance based multi-objective optimization problem that uses fuzzy representation of uncertainty (Bardossy and Duckstein, 1992). Examples of FCP methodology include management of a karstic aquifer (Bardossy and Duckstein, 1992), nitrate risk management (Lee et al., 1992), management of dredged material (Lee et al., 1991) and landfill hazard ranking (Hagemeister et al., 1996).

GENERIC MODEL

Consider the situation where a CIO is resolving an outsourcing decision. At a strategic level, the CIO must balance costs, staffing, market concerns, and technical capability. Figure 1 shows this hierarchy. The *Outsourcing Decision* is composed of *Staffing*, *Costs*, *Market Position*, and *Technical/Functional Appropriateness* elements. Inherently, the decision-maker (DM) must balance these concerns and given particular environments, knows which are most important. A description of each of the factors is given below.

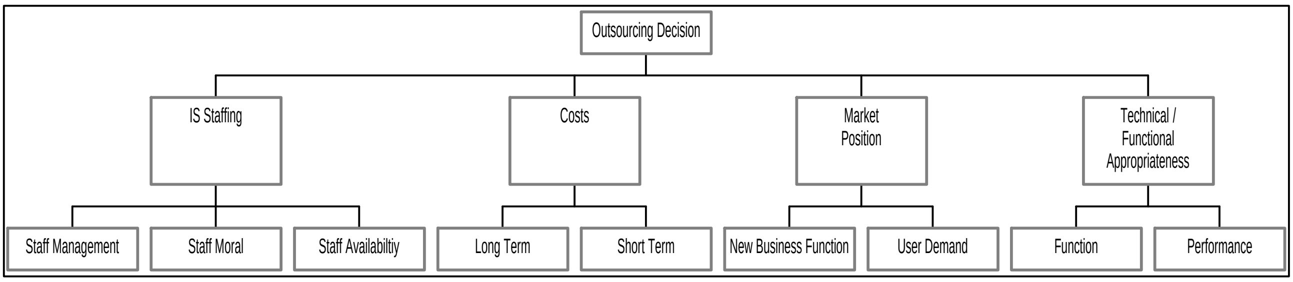

Figure 1: FCP structure for application outsourcing strategic decision making.

STAFFING

Staffing is a major concern in IT today. The need for high quality resources forces this concern to be included in the analysis of strategic decisions. The DM must determine which of the components are most important to the staffing concerns. Appropriate and quality *staff management* is more difficult to obtain given the competitive nature of IT today. Certain implementations require a management capability that may not be typical in a particular IS environment. When change is implemented, maintaining *staff morale* is a concern . It is linked to productivity and must be closely guarded. Industry wide *staff availability* is a crucial concern. Decisions ignoring this reality are suspect.

COSTS

Costs are always a strategic concern. The DM must determine priority and importance *for long term* versus *short term* consequences. More appropriate to our philosophy may be fixed versus variable costs. In either situation, competition exists, not only for the lower costs, but also for the cost strategy that best enables company position.

MARKET CONCERNS

Market concerns become apparent in times of rapidly changing market conditions. The typical scenario is when new products or services are to be delivered and the IS services must accommodate this new condition. The efficacy with which the IS services accommodates *new business function*, becomes competitive with the need for continued *user demand* on existing systems.

TECHNICAL/FUNCTIONAL APPROPRIATENESS

The appropriateness of the technology depends upon the system providing the appropriate *function* with acceptable *performance*. Ideally systems will simultaneously provide these features. However, a well performing system that does not function correctly is not acceptable.

SCENARIO

In order to illustrate this methodology, consider the following hypothetical situation. BCD Inc. is a manufacturing company with an annual IS budget of $10 million. Y2K and market concerns have forced BCD Inc. to examine internal IS strategies. Like many companies of this type, the heart of the information systems is composed of legacy code. Maintenance costs associated with this code are increasing due to loss of expertise (business and technical), Y2K conversion, competition between maintenance and development for resources, and other factors.

Consider specifically the inventory control system. The inventory control system has been developed over the previous 25 years. The programs have been developed using a variety of versions of COBOL. Some parts of the system were obtained when BCD Inc. purchased a small company. The system works adequately but conversions and updates are slow and tedious. The introduction of new product lines was delayed because of inadequate update cycle times. Adequate testing is difficult due to the distributed nature of the manufacturing facilities.

DESCRIPTION OF DECISION MAKING ENVIRONMENT

Prior to examining alternatives the DM must describe the constraints and decision making criteria needed to objectively evaluate alternatives. Generally this is an internal process that is not typically well defined or thoroughly documented. The description is in part the structure of the contributing factors as illustrated in Figure 1, but also includes the knowledge and preferences of the DM.

To capture the knowledge and preferences of the DM, ranks are used to indicate the importance of competing issues. Consider first the Staffing group. As illustrated in Figure 1, the Staffing group is composed of Staff Management, Staff Morale, and Staff Availability. The DM must indicate as completely as possible the relative rank and relationship of each of these contributors. For the sake of this example, assume that the DM is most concerned with Staff Availability and least concerned with Staff Management. The resulting weights of the contributors are shown in Table I. Note that within each group, the weights must sum to 1 and each must be between 0 and 1.

Group	**Balancing Factor**	**Contributor**	**Weights**
Staffing	2	Staff Management	0.2
		Staff Morale	0.3
		Staff Availability	0.5
Costs	1	Short Term Costs	0.3
		Long Term Costs	0.7
Market Position	3	New Business Function	0.6
		User Demand	0.4
Technical/Functional Appropriateness	2	Function	0.5
		Performance	0.5

Notes:
1. Weights and balancing factors are valued as real numbers to simplify the example for illustrative purposes. The goal is to capture the intent of the DM and describe that intent in mathematical terms. The weights and balancing factors could be valued as fuzzy variables, ranks, or scaled ranks to provide a more realistic description of the contributing factors.
2. Balancing factors are not well defined in current literature. However, analysis implies that as the balancing factor increases, the less influential the weights become. Therefore, the practical application of the balancing factor is not lost since limiting the balancing factor to modest levels seems appropriate.

Table I: Weights and balancing factors for each contributing factor.

Consider also the Costs group. The Costs group is composed of Short Term Costs and Long Term Costs. The DM realizes that the existing situation is financially stable enough to concentrate on long term issues and can withstand any short term difficulties provided the long term benefits are realized. Similar analysis is provided for each of the other groups and is also presented in Table I.

Also included in Table I is the balancing factor. The balancing factor is a computational necessity and is a measure of the exchangeability of the contributors to each group. To illustrate this, consider the Costs group. The goal is to combine the concerns of Short Term Costs and Long Term Costs. In this case it is easy to compare them since the common unit is dollars and therefore a balancing factor of 1. This is similar to comparing ‘Apples to Apples’. Contrast this to the Market Position group which was assigned a balancing factor of 3. The goal is to combine the concerns of New Business Function and User Demand. There exists no common unit yet they must be combined. This is analogous to comparing ‘Apples to Oranges’. By extension then it becomes obvious that the Staffing group falls somewhere between the previous two explanations and was assigned a balancing factor of 2. This is analogous to comparing ‘Red Delicious Apples to Jonathan Apples’. The utility of the balancing factor is to combine and compare dissimilar interest.

This process is repeated to combine all of the groups into an overall Outsourcing Decision. The combination of each of the groups is accomplished by ranking the groups as to importance by assigning weights to each and by assigning a balancing factor to the combination. Since the groups represent vastly dissimilar interests a balancing factor of 3 is assigned. The ranking, as expressed through the assignment of weights, is shown in Table II. Note that the weights sum to 1 and that each weight is between 0 and 1.

Overall Decision	Balancing Factor	Group	Weights
Outsourcing Decision	3	Staffing	0.2
		Costs	0.35
		Market Position	0.35
		Technical/Functional Appropriateness	0.1

Table II: Weights and balancing factors for each group.

DESCRIPTION OF ALTERNATIVES

Four alternatives have been developed from which to choose; the last alternative is to remain status quo. Each alternative has various costs and consequences that will impact the selection of that alternative. The consequences of each of these strategies are listed below and summarized in Table III.

	Alternatives			
Contributors	A	B	C	D
Staff Management	Negative	Neutral	Negative	Positive
Staff Morale	Positive	Negative	Neutral	Neutral
Staff Availability	Negative	Positive	Neutral	Neutral
Short Term Costs	≈$4 million	$3 million	≈$4 million	$2.5 million
Long Term Costs	≈$3 million	$3 million	≈$4 million	≈$5 million
New Business Function	Positive	Neutral	Neutral	Negative
User Demands	Negative	Positive	Neutral	Neutral
Function	70% - 80%	85% - 95%	80% - 90%	85% - 95%
Performance*	100,000	70,000	90,000	34,000

* operations per day

Table III: Summary of outcomes of alternatives.

ALTERNATIVE A: IMPLEMENT PACKAGED APPLICATION.

The old inventory control system is abandoned and a new inventory control system is implemented using a well-developed packaged application. The consequences of adapting this strategy are as follows:

Staff Management

Negative. Currently on staff, the management expertise does not exist to guide this type of conversion. The vendor of the packaged application offers management consulting but that alternative does not allow for appropriate utilization of current management.

Staff Morale

Positive. Staff morale would improve significantly with this alternative. Many of the newer hires have recognized the antiquated nature and lack of standards of the current code and are ready to engage in newer, standardized technology. This will also give some of the original developers an excuse to conclude their careers.

Staff Availability

Negative. The dual requirements of implementing a new package and maintaining the existing system will stretch the current staff. Hiring on the open market has been limited and consulting costs are prohibitive.

Short Term Costs

About $4 million. The costs associated with this implementation are estimated to be about $4 million. These costs could be as low as $3.5 million or as high as $5 million. A fuzzy representation of these costs is shown in Figure 2.

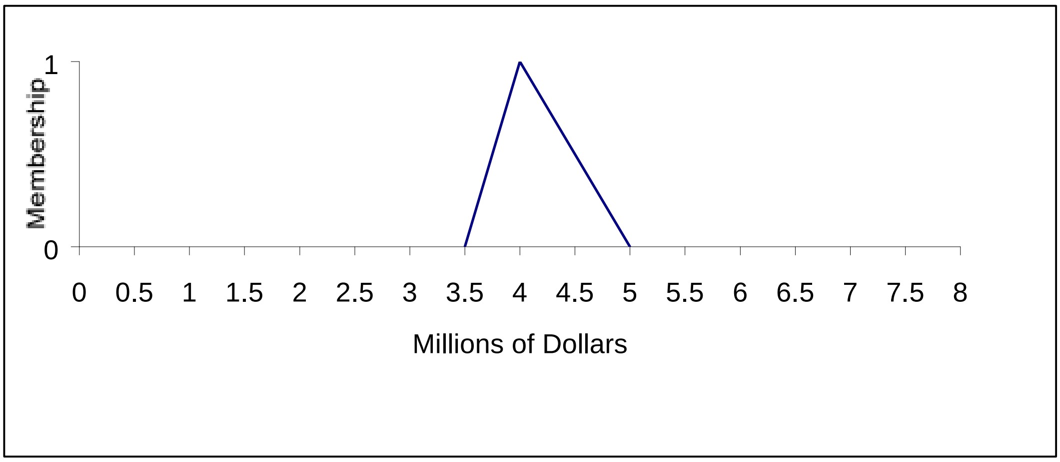

Figure 2: Fuzzy representation of short term costs for alternative A

Long Term Costs

About $3 million. The costs associated with this implementation are estimated to be about $3 million. These costs could be as low as $2.5 million or as high as $6 million. A fuzzy representation of these costs is shown in Figure 3.

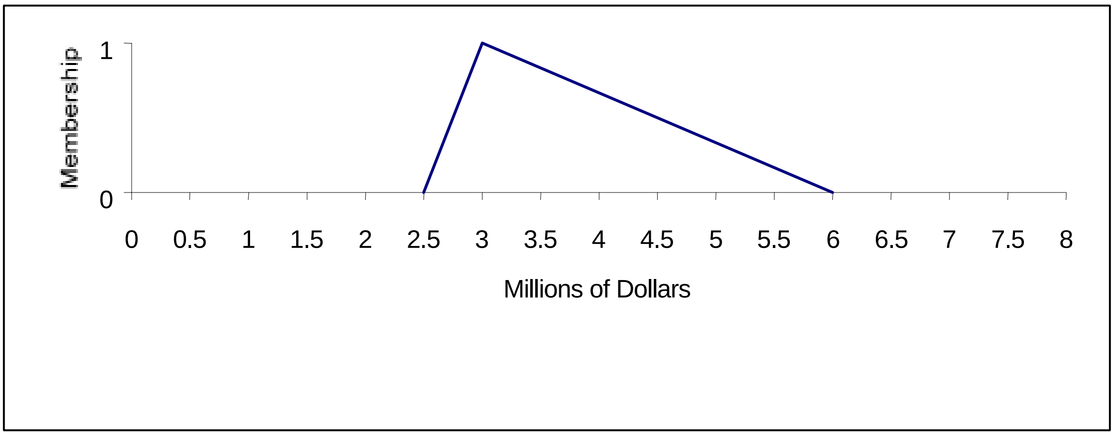

Figure 3: Fuzzy representation of long term costs for alternative A

New Business Function

Positive. One of the strengths of the proposed packaged application is that it is easily adjusted for new business rules.

User Demand

Negative. Since the proposed packaged application is not custom designed for the users, user acceptance and demand will likely not be good.

Function

Neutral. The proposed packaged application has most of the functionality needed. The shortcomings exist because it is not a custom design. A fuzzy representation is shown in Figure 4.

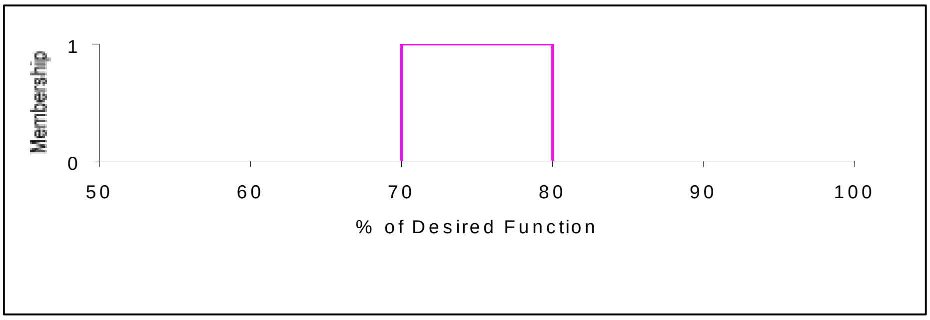

Figure 4: Fuzzy representation of function for alternative A

Performance

100,000 operations per day. The proposed packaged application uses a database management structure that will shorten the current long batch oriented processes. It is estimated that this system will perform 100,000 operations per day.

ALTERNATIVE B: MAINTAIN THE SYSTEM AS IS USING APPLICATION MAINTENANCE OUTSOURCING.

The old inventory control system is maintained in an outsourcing arrangement with consultants who provide: a specialized methodology, industry experience, and expertise on the current system platform and languages. The consequences of adapting this strategy are as follows:

Staff Management

Neutral. Currently on staff, the management expertise exists to guide this type of arrangement.

Staff Morale

Negative. Staff morale would decrease due to the worries associated with displacement of job opportunities.

Staff Availability

Positive. The responsibility of staffing is transferred to the outsourcing vendor.

Short Term Costs

$3 million. The vendor is agreeable to a fixed price.

Long Term Costs

$3 million. The vendor is agreeable to a fixed price.

New Business Function

Neutral. The vendor is inhibited by the existing code but can bring substantial resources to address new functionality.

User Demand

Positive. The users will not be required to change systems and response time and maintenance will improve.

Function

85% - 95%. The software is a custom design application and will continue to provide targeted function estimated to be 85% to 95%. A decrease to 80% is possible given new maintenance procedures. A fuzzy representation is shown in Figure 5.

Performance

70,000 operations per day. Maintenance practices will not speed performance but will likely enhance availability of resources. It is estimated that this system will perform 70,000 operations per day.

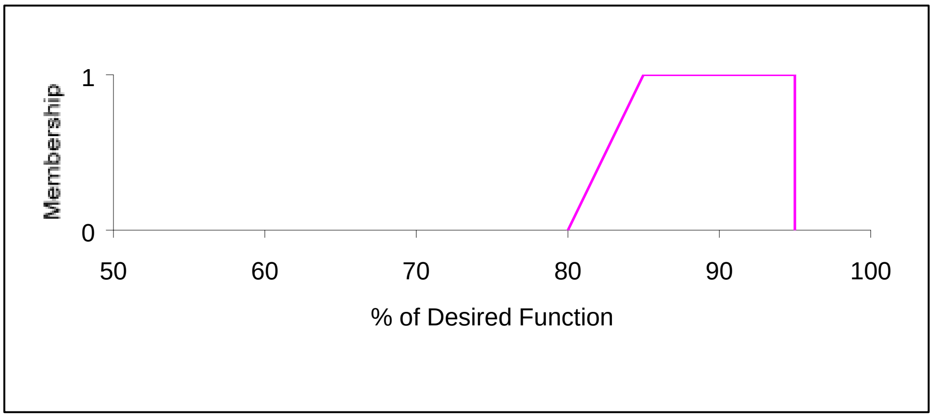

Figure 5: Fuzzy representation of function for alternative B

ALTERNATIVE C: MIGRATION TO CLIENT SERVER ENVIRONMENT

The existing system is ported to a client-server environment that offers the flexibility of distributed computing and data storage. The consequences of adapting this strategy are as follows:

Staff Management

Negative. The expertise associated with a client-server environment is not on staff and is at a premium in the market.

Staff Morale

Neutral. A change in technology will simultaneously energize and discourage the staff.

Staff Availability

Neutral. Client-server experience is in short supply on the open market. However, there are resources in house that can be retrained.

Short Term Costs

About $4 million. The transition costs are approximately $4 million. These costs could be as low as $3 million. A fuzzy representation of these costs is shown in Figure 6.

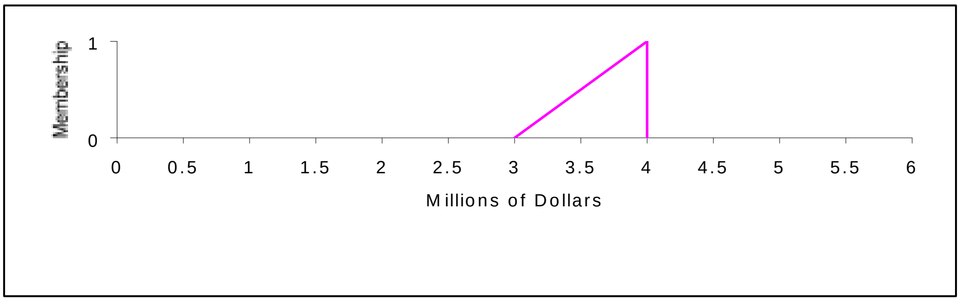

Figure 6: Fuzzy representation of short term costs for alternative

Long Term Costs

About $3 million. The costs of maintaining systems in the future will be expensive. This is high because the technology is still developing in the client-server environment. The costs could be as low as $1 million given the expectation of new maintenance tools in the client-server environment. The cost could be as high as $4 million. A fuzzy representation of these costs is shown in Figure 7.

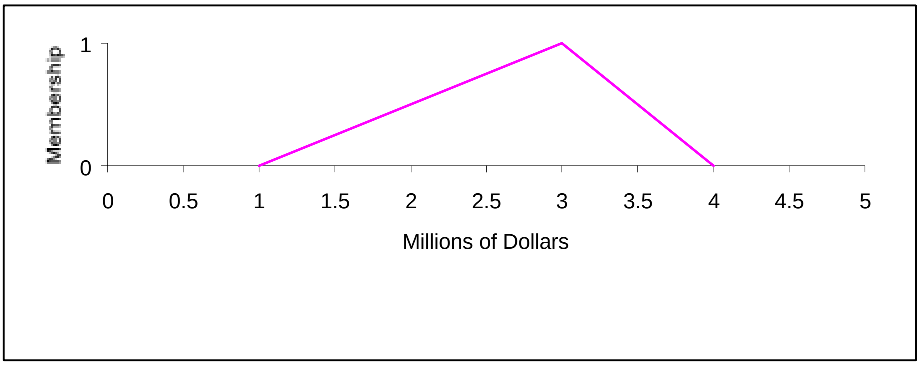

Figure 7: Fuzzy representation of long term costs for alternative C

New Business Function

Neutral. The existing code is partially portable to the client-server environment. Additional functionality must be developed under normal processes.

User Demand

Neutral. User adoption is likely to be achieved easily with the ported code. Adoption of newly developed code will be an issue.

Function

80% - 90%. The implementation of the new environment is largely a conversion so functionality should be high. Additional development will decrease functionality.   A fuzzy representation is shown in Figure 8.

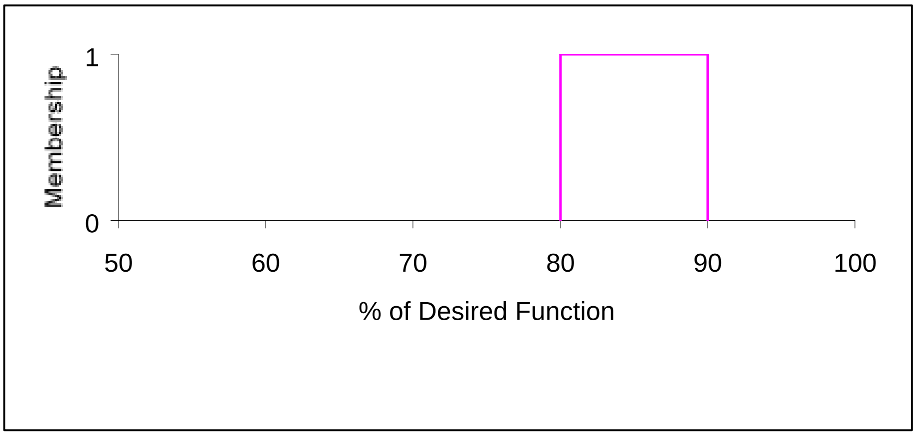

Figure 8: Fuzzy representation of function for alternative C

Performance

90,000 operations per day. Client-server environments will enhance the existing performance over the existing batch oriented process. It is estimated that this system will perform 90,000 operations per day.

ALTERNATIVE D: DO NOTHING

The do nothing alternative is always an option and must be considered. The consequences of continuing the current strategy are as follows:

Staff Management

Positive. Staff management is currently adequate.

Staff Morale

Neutral. Staff morale is currently not as good as it should be. There is some comfort in the static condition.

Staff Availability

Neutral. There would be no motivation to expand the staff.

Short Term Costs

$2.5 million. The current costs of maintenance are $2.5 million and no new short term costs will be incurred.

Long Term Costs

About $5 million. The costs of maintaining systems in the future will be expensive. This is high because the cost of maintaining legacy code will continue to increase as expertise becomes less available. The long term costs will not be less than the current costs of $2.5 million. It is estimated that these costs will double to $5 million and perhaps triple to $7.5 million. A fuzzy representation of these costs is shown in Figure 9.

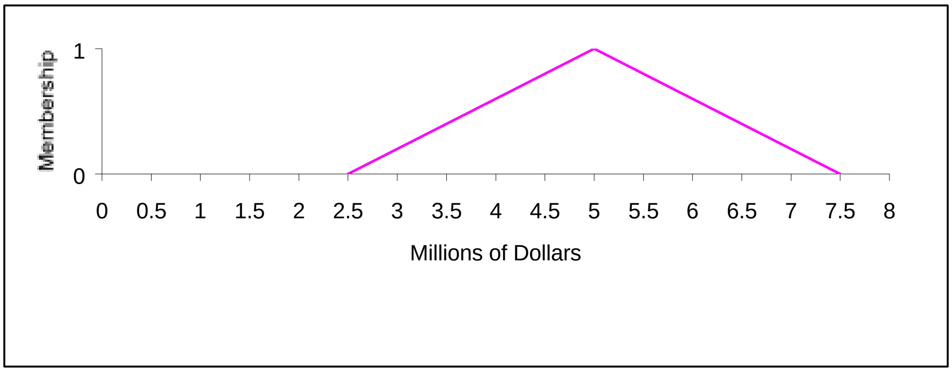

Figure 9: Fuzzy representation of long term costs for alternative D

New Business Function

Negative. The existing code is not well suited for these changes.

User Demand

Neutral

The users will not be required to change systems and but response time and maintenance will continue to be an issue.

Function

85% - 95%. The software is a custom design application and will continue to provide targeted function estimated to be 85% to 95%. A fuzzy representation is shown in Figure 10.

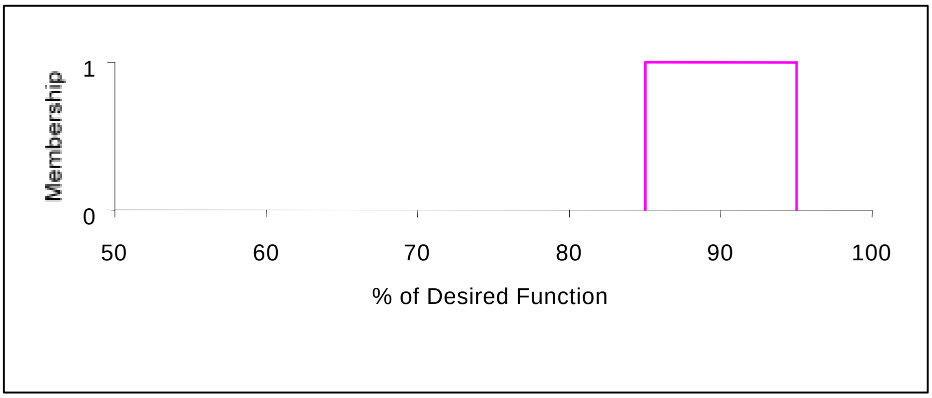

Figure 10: Fuzzy representation of function for alternative D

Performance

34,000 operations per day. Batch oriented process are beginning to inhibit performance in some areas. It is estimated that this system will perform 34,000 operations per day.

CONVERSION OF LINGUISTIC VARIABLES TO ARITHMETIC EXPRESSIONS

Consequences expressed as linguistic variables are obviously an over simplification. However, for the DM in the early stages of model development, it is probably more practical to describe contributors in terms like 'negative, neutral, and positive' or 'very high, high, medium, and low' than in numerical values. In reality these consequences will be expressed appropriately as numeric values, fuzzy values, etc. In this case the linguistic expressions are converted to arithmetic expression for computational purposes. The values are selected as shown in Table IV.

Linguistic Variable	**Numeric Value**
Negative	-1
Neutral	0
Positive	+1

Table IV: Description of Linquistic Variables

A fuzzy representation is shown in Figure 11.

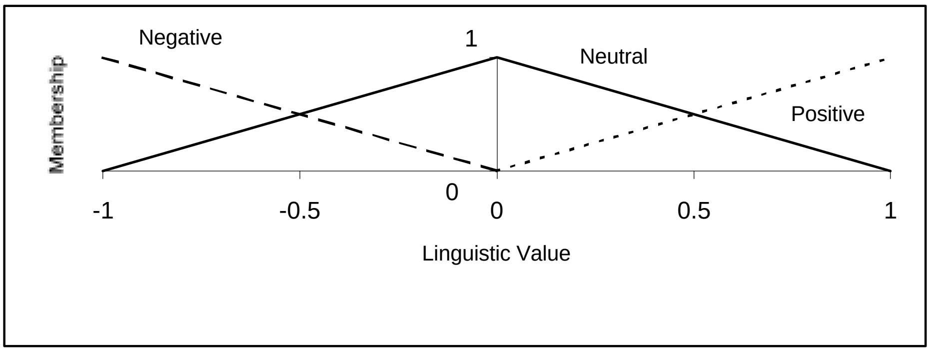

Figure 11: Fuzzy representation of linguistic variables

DESCRIPTION OF 'WORST' AND 'BEST' PARAMETERS

The computational algorithms require scaled values therefore 'Worst' and 'Best' values for each contributor must be determined. Similar to each of the other values, these values can be linguistic, crisp, fuzzy, etc. The 'Worst' and 'Best' values used in this example are shown in Table V.

The 'Worst' and 'Best' values for the Costs contributors were determined directly form the fuzzy representations of each of the costs. The worst case of the short term costs corresponded to a cost of $5 million whereas the best case corresponded to a cost of $2.5 million. The 'Worst' and 'Best' values for the long term costs are similarly determined.

The 'Worst' and 'Best' values for the function contributor was determined directly form the fuzzy representations of each of the variables. The worst case corresponded to 70% functionality whereas the best case corresponded to 95% functionality.

The 'Worst' and 'Best' values for the Performance contributor are determined by evaluating performance demand. The current situation dictates that at least 20,000 operations per day are required and perhaps as many as 30,000 operations per day are required. As the business expands, it is anticipated that the demand could be 120,000 operations per day and perhaps as much as 150,000 operations per day. A fuzzy representation of each of these values is shown in Figure 12.

Contributors	Worst	Best
Staff Management	0	1
Staff Morale	0	1
Staff Availability	0	1
Short Term Costs	$5 million	$2.5 million
Long Term Costs	$7.5 million	$2.5 million
New Business Function	0	1
User Demands	0	1
Function	70%	95%
Performance*	20-30,000	120-150,000

*operations per day

Table V: Worst and Best values for each contributor.

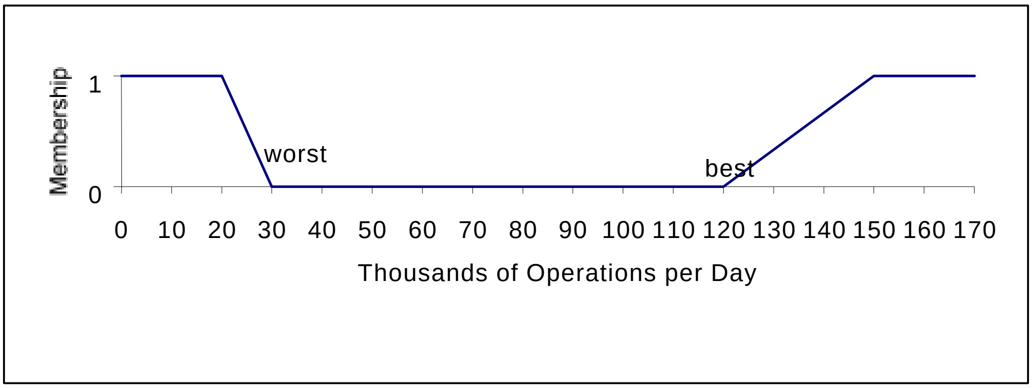

Figure 12: Fuzzy representation of worst and best indicators for performance contributor.

The computational aspects of the problem solution begin with normalization. Each of the input variables must be normalized. The normalization is performed with the following equation (Bogardi, 1992 and Hagemeister et al. 1996).

$$\tilde{S}_i = \frac{\tilde{Z}_i - Z_{i-}}{Z_{i+} - Z_{i-}} \quad \text{when } Z_{i+} \text{ is best, or}$$

$$\tilde{S}_i = \frac{Z_{i+} - \tilde{Z}_i}{Z_{i+} - Z_{i-}} \quad \text{when } Z_{i-} \text{ is best}$$

where $\tilde{S}_i$ = normalized i^th fuzzy indicator;
$\tilde{Z}_i$ = value of the i^th fuzzy indicator;
Z_{i+} = maximum possible value of the i^th indicator; and
Z_{i-} = minimum possible value for the i^th indicator.

The hierarchical structure of this technique is used to aggregate the first–level fuzzy indicators into more complex second (and higher) fuzzy level indicators. This process is of aggregation continues until the final-level fuzzy indicator is achieved.

The final result will include inevitable uncertainties and ambiguities due to imprecise first level indicators. Their structure can be established such that first-level indicators will utilize known or relatively easily obtained information, which lead to ranking or assessment of a very complex system. Additionally, the first-level indicators must fundamentally characterize the state of the system. The units and magnitude of first-level indicators are not critical because distances are normalized.

The sets of related normalized first-level fuzzy indicators are combined to obtain their respective second-level fuzzy composite distance. The process of computing successive levels of fuzzy composite distances is repeated until a final fuzzy composite distance is reached for the system. This final-level fuzzy indictor composite distance represents the compliance of the particular alternative to the description of the ideal solution as measured by a fuzzy composite distance. The fuzzy composite distance is obtained by the following equation (Bogardi, 1992 and Hagemeister et al. 1996).

$$\tilde{L}_j = \left(\sum_{i=1}^{n_j} w_{i,j} \cdot \tilde{S}_{i,j}{}^{p_j} \right)^{1/p_j}$$

where, $L^{\sim}_j$ = fuzzy composite distance for group j of the indicators;
$S^{\sim}_{i,j}$ = normalized fuzzy value of the input element indicator i in group j;
$\omega_{i,j}$ = weights expressing the relative importance of indicators in group j such that their sum is 1;
$p_{i,j}$ = balancing factors among indicators for group j; and
n_j = number of indicators in group j.

RESULTS AND DISCUSSION

A spreadsheet calculator was developed to perform the calculations. The results are shown in Figure 13. The x-axis in Figure 13 is the fuzzy distance towards the ideal solution. A value of 1on the x-axis would indicate that the ideal solution has been achieved. A value of 0.5 indicates that the solution is one half the distance between the worst solution and the ideal solution. The y-axis indicates the membership (or degree of belonging) of each alternative to its position towards the ideal solution.

The results in Figure 13 can be interpreted by saying that Alternative B will most likely perform between 0.78 and 0.80 of the ideal solution; it could perform as low as 0.59 or as high as 0.91 of the ideal solution. Each of the alternatives could be similarly interpreted.

There are several ways to ‘defuzzify’ results such as those presented in Figure 13. The techniques include determining centers of mass, weighted averages, etc. For this example, the practical interpretation is to choose the alternative that most closely conforms to the description of the ideal solution. The breadth, or spread, of the curves representing each alternative in Figure 13 is meaningful. The ambiguities captured in the first level indicators have been propagated through the systems and are now manifest in Figure 13. A wider spread represents more ambiguity or uncertainty. Conversely, a tighter spread indicates less ambiguity or uncertainty.

This approach to decision making is useful for a variety of reasons, including that it:

- allows users to express individual or corporate values and preferences;
- highlights degree of imprecision associated with each input;
- highlights degree of imprecision associated with each alternative;
- facilitates structuring of the decision process;
- allows examination of trade-offs between alternatives and interests; and
- forces examination of inter-relationships between interest.

The example illustrated in this work demonstrates how IT decisions can be documented, communicated and analyzed with potential to provide better decisions. This technique is applicable to generic decision making processes.

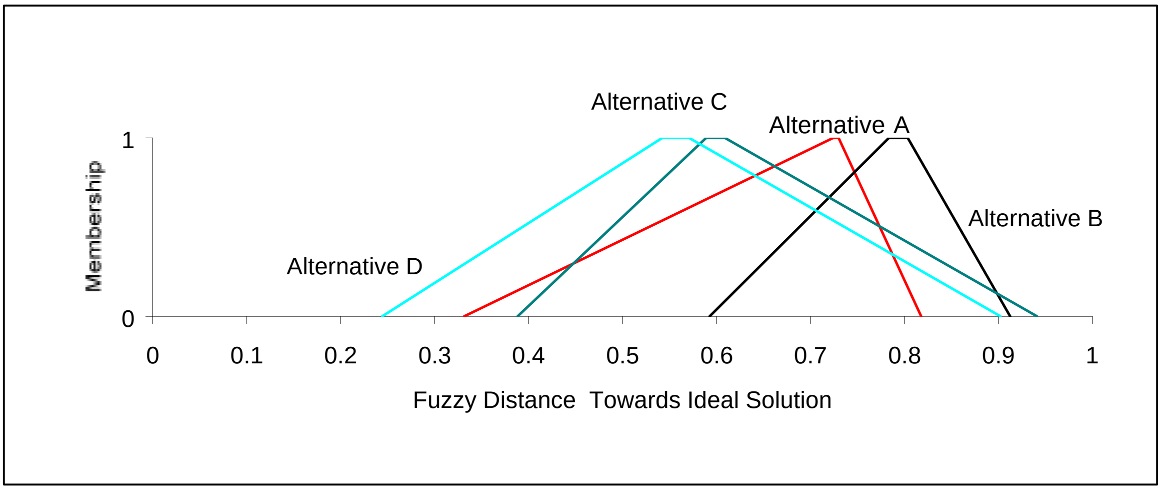

Figure 13: Fuzzy representation of composite decisions of each alternative

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