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Developing a comprehensive methodology for computer-family selection

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THESIS

DEVELOPING A COMPREHENSIVE METHODOLOGY
FOR
COMPUTER-FAMILY SELECTION

by

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September, 1989

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Developing a Comprehensive Methodology for Computer-Family Selection

by

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I. INTRODUCTION

As the computing needs of an organization expand, the decision to add to, or replace, existing computer systems is important and may have long term effects on an organization. The impact can be financial, operational or both. The choice of computer systems, hardware and software will be a major factor in defining the information processing capabilities of an organization. The methods for selecting computer systems are varied and have evolved over the past 20 years.

Computer systems have become less expensive and, at the same time, significantly more powerful. Advances in data communication technology have led to the increased use of distributed data processing (DDP) and decentralized computer systems. In order to effectively use DDP and decentralized computing, computer systems throughout an organization must be compatible with each other. Data and files have to be transferable and useable on all systems throughout an organization.

Once a decision is made to acquire a new computer system, an organization needs to ensure that its selection is the best choice to meet its present and future computing needs. If the selected computer system does not fulfill the organizational requirements there might not be another chance to make a better choice due to cost and time constraints.

The emphasis of this thesis is on the evaluation and selection phases of a computer system acquisition process. The actual selection of a computer system is preceded by several procedural steps. The following is a generalization of those procedures:

- Analyzing the requirements and computing needs of the organization.
- Determining and defining the requirements for the computer system.
- Sending the request for proposal (RFP) to qualified vendors.
- Screening, evaluating, validating and comparing the proposals.
- Selecting the computer system.

From the multitude of computer systems, operating systems, software and peripherals, a user has to choose those products that best meet an organization's needs. The difficult task facing those responsible for the selection is to determine by what standards competing systems are compared and evaluated.

Traditional procedures have addressed the selection of individual computer systems. With DDP and decentralized computing becoming more prevalent, there is a need to apply new methods for selection. The concern is no longer the selection of a single system; it is the selection of a group of systems that work together and enable the sharing of files and data.

II. COMPUTER SELECTION PROCEDURES

As long as there has been more than one computer system available to meet a user's requirements, there has been a need to select the one that best fits the job. The problem is how to make that selection. There have been a number of models and methods proposed and used to select computer systems. The various methods used have concentrated on the individual stages in the selection process and on specific techniques for each stage.

The selection process consists of several stages: analysis of needs, determination of requirements, request for proposals, evaluation of proposals and selection of a system. The first two steps are preliminary to the evaluation of the proposals, while the latter two are often blurred into a single step: evaluate the candidates and pick the best.

The techniques for the evaluation of computer systems generally are either simple or sophisticated. The simple methodologies are basically intuitive, unsupported by any theory or lacking a systemized approach. The sophisticated methods employ an analysis of vendors' proposals with a ranking of the proposed computer systems. Following this ranking, a hardware performance and capability analysis is performed on the most desirable alternatives. If the system that was ranked first fails to perform adequately then that system is rejected and analysis is carried out on the next highest ranked system.

The most commonly used computer system evaluation methods are:

Weighted Scoring. This commonly used approach attempts to overcome evaluation problems by combining objectivity with consideration of apparently non-quantifiable factors. Relative weights are pre-assigned to all system items considered important. Each competent system is subjectively rated with respect to each selected system item and then the overall score is computed for each vendor. The rating is subjective: from "no good" to "entirely adequate". The system with the highest total score is considered most desirable. (Borovits and Zviran, 1987)

The advantage of this method is that it is simple. It also enables one to perform sensitivity analysis of the results for changes in the importance weights of the attributes. Its disadvantage is that it is not normative, i.e. it is not based on a system of axioms expressing rational behavior rules expected of a decision maker. Thus, it does not require an examination of assumptions of independence in the attributes and the absence of such an examination may result in deviations. (Shoval and Lugasi, 1987) The following example demonstrates this:

Two proposals, A and B, are examined according to two independent attributes, "vendor support" and "hardware performance". If A and B receive the same score in the evaluation and if "vendor support" is evaluated as entirely adequate in proposal A and no good in proposal B while "hardware performance" is entirely adequate in B and no good in A, then the "hardware performance" of B may never be available because of its no good "vendor support". (Timmreck, 1973)

This method does not allow for an examination of consistency of the evaluators. Due to its nature, the method does not consider risk and uncertainty. It should be noted that granting scores in every attribute is in itself a difficult task and influenced by subjective considerations. (Shoval and Lugasi, 1987)

Multi-Attribute Utility Model. Shoval and Lugasi (1987) use of Keeny's multi-attribute utility model allows an evaluation of the utility function of the attributes and the calculations of their weights. It differs from other models in that it considers risk and uncertainty.

The application of the model requires both utility and preference independence. Utility independence claims that for attributes X1...Xn the utility of attribute Xi does not depend on the remaining attributes. Preference independence claims that preference between every pair of attributes does not depend on the fixed level of remaining attributes.

There are two variants, which differ in the way they refer to risk, the additive model and the multiplicative model. The application of either depends on a decision maker's attitude towards risk.

In order to evaluate the utility function of the attributes and to calculate the weights/constants of the attributes, a gambling technique is used, a utility function of the Von-Neuman-Morgenstern type.

Evaluation of the decision maker's utility function is based on the axioms of transitivity and continuity. If these axioms are satisfied, it is possible to form a utility function for the decision maker for each attribute.

The multi-attribute utility model is normative, since it forces a decision maker to accept a set of axioms which express preferences and it also requires an examination of independence assumptions before the model is applied. The model also enables one to make sensitivity analyses. Compared with other models this model is more difficult for the decision maker to understand and apply, since determining a probability at which a decision maker is indifferent between alternatives is not always clear and acceptable. (Shoval and Lugasi, 1987)

Cost-Effectiveness Ratio. This is simply a sub-category of the weighted scoring technique, where the cost of the entire computer system is divided by the sum of its points. The system having the highest total score is considered the most desirable. (Borovits and Zviran, 1987)

Cost-Value. This approach uses cost as the sole measure. Cost and benefits are assigned to the desirable features of each proposed system. The sum of these values is then subtracted from the total cost of the system. The result represents the cost of the system to meet to meet the mandatory requirements. The system with the lowest cost is the most desirable. (Timmreck, 1973)

Requirement-Costing Technique. Here the estimated cost-savings benefits are assigned to a set of desirable features. Those not part of the proposed system are then added to the total cost of the system. In addition, if a desirable feature is offered at an additional cost that is less than the estimated benefit, the incremental cost is added to the system cost. The system with the lowest resulting cost is considered the most desirable. (Borovits, 1984)

Dynamic Approach. This approach employs a projected work load growth trend and cost-effectiveness ratios of each vendor's proposed product line. The underlying assumption is that it would be feasible to install a system for as little as one year, but only if it will be replaced by a compatible system from the same manufacturer's product line and replacement accords with the dictates of work load. Using the projected work load trend and measurement of system capacity, a schedule of replacement is worked out. The cost of each system (as determined by one of the methods described above) over the period of its employment is then discounted with respect to an estimate of cost of capital and its expected future life. The product line with the lowest discounted present cost is the most desirable. (Ein-Dor, 1977)

Present Value Analysis. The objective here is to determine which system will cost the least and benefit the organization most. The net present value of the proposed system should be determined by discounting all cash flows associated with it, using an organization's cost of capital as the discount rate. The benefits projected by the proposed new system are the net cash inflows. The system with highest net present value is the most desirable. (Borovits and Zviran, 1987)

Efficient-Frontier Model. In this model, the preferred system is that which is dominant in all the attributes considered according to a decision maker's preference.

This method enables one to screen out alternatives that are inferior in all attributes or are identical in some and inferior in at least one. The alternatives remaining after this screening form an "efficient frontier". There remains the problem of selecting a preferred alternative; this requires other methods. Therefore, this model is not sufficient. It is applicable, at most, in performing initial screening. (Shoval and Lugasi, 1987)

Lexicographical Ordering. In this model, alternatives are rank-ordered according to a dominant attribute, the most important one, e.g. CPU power. Clearly, this is possible only if a dominant attribute exists and cannot be traded off with others. This model can, at most, help in the initial screening of alternatives which are deficient in an important attribute but it cannot choose the best. (Ahituv and Neumann, 1986)

III. COMPUTER-FAMILY SELECTION

The selection procedures being discussed focus on the selection of a group of systems that will work together, sharing files and data. This group of systems has been called a computer-family and defined as:

> **Computers of the same type, consisting of several models from the same manufacturer's product line, ranging from microcomputer to mainframe, with full compatibility in the operating system and the system's software, to enable transfer of application software from one family member to another without change.**
> (Borovits and Zviran, 1987)

An example of a computer-family is Digital Equipment Corporation's (DEC) VAX 8840 mainframe computer, VAX 6220 minicomputer and Microvax 3600 super-microcomputer. Another example consists of a Prime 6650 mainframe computer, a Prime 4450 minicomputer and a Model 4050 super-microcomputer.

Selecting a computer-family is a more complex process than selecting a computer system. The process will have a lasting effect on an organization because there will be one computer-family from which current and future hardware acquisitions will be made. This will help ensure uniformity and compatibility in information processing throughout an organization.

For DDP and decentralized computing the compatibility obtained in hardware and software will preclude the systems integration problems encountered while using mismatched systems. The benefits of system-wide compatibility are exemplified by the ability to transfer application software from one family member to another using a common operating system.

A number of methods are used for computer system selection. Some of the concepts presented in the existing methodologies form the basis for a methodology to deal with computer-family selection. The procedures presented here are a ten-step generic evaluation and selection methodology. (Borovits and Zviran, 1987)

Figure 1 portrays a work flow diagram of this process. The work flow diagram highlights the processes that occur after an analysis of an organization takes place and systems' requirements document are developed.

The stages in this process are:

Step 1. Identification of possible vendors and manufacturers: After studying the requirements document it may be determined which manufactures or vendors may be able to provide products that will meet an organizational needs.

Step 1. Identification of possible vendors and manufacturers.

↓

Step 2. Primary elimination of irrelevant candidates.

↓

Step 3. Determination of mandatory requirements.

↓

Step 4. Examination of vendors' compliance with mandatory requirements.

↓

Step 5. Setting quantitative and qualitative criteria and respective weighting scales.

↓

Step 6. Writing the RFP to be addressed to selected vendors.

↓

Step 7. Receiving, comparing and analyzing bids.

↓

Step 8. Concluding final list of vendors.

↓

Step 9. Performance of hardware and software benchmarks.

↓

Step 10. Drawing final conclusions and selection of best computer-family.

Figure 1. Selecting a computer-family: a work flow diagram. (Borovits and Zviran, 1987)

A list of possible vendors can be generated and used in future stages.

Step 2. Preliminary elimination of irrelevant candidates: Further study of an initial list of manufacturers and vendors should reveal apparently unsuitable candidates. They should be pared from the original list to produce a manageable list of potential (relevant) vendors. Reasons for elimination are for unsuitability in meeting requirements or because they do not have a complete computer-family.

Step 3. Determination of mandatory requirements: From the systems requirement document and from organizational policy certain features and characteristics of a computer-family are identified as prerequisites for further consideration. These are criteria that must be met by any potential computer-family.

Step 4. Examination of vendor's compliance with mandatory requirements: On the basis of mandatory requirements, a questionnaire is formulated and addressed to all relevant vendors. Responses to this questionnaire provide a selection committee with basic information about proposed computer-families and each product line. The responses are screened to determine if they meet mandatory requirements. The vendors remaining after this elimination procedure constitute a mailing list for requests for proposals (RFP).

Step 5. Setting quantitative and qualitative criteria and respective weighting-scales: The variability of the capabilities and performance characteristics of each element (hardware, software, service) of a computer system is very large, and the number of permutations is considerable. A properly constituted set of quantitative and qualitative criteria is critical for the acquisition of a satisfactory computer-family. Furthermore, vendors are expected to propose not a single computer system but rather a wide product line of systems working together. This raises a problem of evaluating and comparing proposals. Borovits and Zviran (1987) suggested that the quantitative selection criteria be applied to at least the following five issues, each of which has its own partial list of guidelines.
[Fig. 2]

HARDWARE (for each model within the family)
* memory size (minimum, maximum, units of expansion)
* disks (number of drives, minimum and maximum capacity)
* tapes (maximum number of drives, density)
* diskette readers (diskette size, density)
* terminals
* printers
* backup features
* miscellaneous

SOFTWARE (for the entire family)
* system software (uniformity of operating system, compilers, utilities, etc., throughout the family)
* programming languages (compilers and interperters, options and extensions, adherence to standards)
* development tools (existence of application generators, report generators, full screen editor, debugging aids, macro facilities, etc.)
* additional software (electronic-spreadsheet, word-processor, electronic-mail, DBMS, etc.)
* ability to transfer software within the family (source modules, load modules, procedures) without change or conversion

COMMUNICATION
* communication protocols
* existence of LAN, possibilty of connection to LAN
* possibilty to transfer files, programs and procedures through communication
* network transfer rate

CONVERSION
* possibilty to convert application software (programs and procedures) from present system to proposed computer-family

ENVIRONMENT
* environment requirements (such as airconditioning,temperature, humidity, etc.)

Figure 2. List of criteria. (Borovits and Zviran, 1987)

Certainly not less important, though non-quantifiable, are qualitative criteria such as:

- how widespread is the use of the proposed computer-family
- vendor support, such as training, maintenance philosophy and practice
- software houses specializing in the proposed computer-family
- current users' opinions and vendor's reputation

Once a detailed and complete set of data relating to all criteria is collected, weights are assigned to all items, both qualitative and quantitative, indicating their relative importance. These weights are fundamental to the evaluation process, explicitly indicating that the objective of the evaluation process is to ensure the selection of a computer-family that best fits the needs (present and future) of an organization.

Step 6. Writing the RFP to be addressed to selected vendors: The primary advertising medium is the RFP, which is issued by a procuring organization and contains the system requirements. Typically, the RFP will include a summary list of specific requirements according to which the vendors will be asked to write their proposals, describing how they will meet each requirement. The RFP should consist of two major parts, the first relating to each model within the computer-family and the second to the computer-family as a uniform entity. The second part is more general in nature and concentrates upon such issues as system software, conversion of present application software to the new computer-family, environment, etc. The RFP should be addressed to those vendors satisfying mandatory requirements.

Step 7. Receiving, comparing and analyzing bids: The problem of analyzing and comparing bids is particularly important, since it is more than possible that none of the computer-families under consideration may exhibit a clear dominance over others. This stage is, therefore, fundamental to the interim evaluation and selection process and should be accorded an appropriate measure of time and effort. It is required that the bids be submitted in writing and it is expected that they will conform to the style indicated in the RFP, so that the selection process will not be affected by style of expression and use of selling techniques.

The first step in the process of analyzing bids to subjectively rate each competing system with respect to each evaluation criterion. A score is assigned to each item. The weighted score is then computed for each proposed system. The next stage is the most problematic since there are no methods or guidelines for comparing computer-families. The proposed method consists of the following steps:

- Five categories of computers are established:

  microcomputers (single station)

  super-microcomputers

  minicomputers

  super-minicomputers

  mainframe computers

These categories represent differences in computing power and other major hardware characteristics.

- Relative weights are assigned to each category according to its importance for an organization.

- Each model within each computer-family is assigned to a category on the basis of criteria such as memory size, maximum number of terminals, maximum disk capacity and relative performance.

- For each criterion, a computer model, or models, is selected within each category, which has dominance over its competitors and the score of 100 is assigned to it.

All other models of the remaining computer-families are then respectively an subjectively scored on a scale of 0 - 100.

- The total score is calculated. The score attained for each criterion is the average weight calculated for all five categories.
- A comparative table is drawn up [Fig. 3] giving the scores attained by each family for each criterion.
- The final score achieved by each family is calculated.

Step 8. Drawing up a final list of vendors: On the basis of the final scores attained by each computer-family a selection committee is able to disqualify irrelevant computer-families, and select up to three or four vendors most likely to succeed. These computer families are then further tested to ensure they have the proper capabilities and characteristics.

Criteria	Vendor A	Vendor B	Vendor C
Crit. 1			
Crit. 2			
Crit. 3			
.			
.			
.			

Figure 3. Outline of comparative table.
(Borovits and Zviran, 1987)

Step 9. Benchmarks for performance of hardware and software: Study of the written proposals is sufficient for evaluating fulfillment of certain requirements. In such cases, benchmarking must be performed. A benchmark, in the context of this discussion, is a set of live tests designed to examine the computer systems (hardware and software) proposed in response to an RFP. Selection of criteria to be tested may be performed according to their importance for an organization using the relative weights already assigned. The purpose of these benchmarks is to verify a system's characteristics before drawing final conclusions.

Step 10. Final conclusions and selection of the best computer-family: After benchmarks have been performed and all essential characteristics of a proposed computer-family have been deemed satisfactory, a selection committee will review and reconsider the relevant scores assigned to each competing computer-family.

Finally, a committee will pick the best as the one recommended to be an organization's computer-family. The recommendations will then be submitted to an organization's management for approval and adoption. A problem faced by those involved in the selection process is how to compare criteria and how to prioritize them according to their importance to the decision making process. There will be a large number of criteria, some quantifiable and others non-quantifiable, whose importance to the selection process will be compared with each other.

IV. THE ANALYTICAL HIERARCHY PROCESS

The methodology developed by Borovits and Zviran (1987) for computer-family selection discussed briefly the process of assigning relative weights to each category of computer in a family being evaluated (Step 5). The process continues with each criterion assigned a relative weight so that it can be evaluated and scored. In a case study by Borovits and Zviran (1987), the assigning of the relative weight and the actual scoring of computers-families was done subjectively.

Using subjective weighting and scoring can reduce the overall effectiveness of the process. There is little precision and it may be difficult to achieve replication using subjective weighting and scoring.

An objective weighting and scoring system can improve this process. An objective weighting system should be characterized by consistency in the assignment of weights. Consistency is a factor that can be computed and compared to a standard. The standard is somewhere less than perfect consistency and greater than intolerable inconsistency. If a standard is exceeded, this indicates randomness in the assignment of values. Should this occur, the criteria should be re-evaluated. (Saaty, 1980)

An objective method that can be adapted for the comparison of a large number of objects, as is the case in comparing computer-families, is the Analytical Hierarchy Process (AHP) developed by Saaty (1977).

The AHP can properly assess the importance of a large number of interacting factors, develop priorities among the factors and choose a best alternative (Saaty, 1980). Seidmann and Arbel (1985) suggested an application of the AHP to the process of microcomputer selection. A large number of or attributes were used to compare microcomputers. The use of AHP allows the determination of both weights and scores for each attribute for each alternative, using matrices to perform pairwise comparisons between alternatives. Once weights and scores are obtained, the final score of each alternative is calculated according to a weighted scoring technique.

In order to determine the weights of n attributes, a decision maker fills up a matrix with dimensions n x n in which a pairwise comparison is made between every two attributes. (Fig. 4) Thus, in each cell (i,j) in the matrix, a decision maker expresses the relative importance of attribute i with respect to attribute j. (It is only necessary to fill up half of the matrix since $a_{i,j}$ is the reciprocal of $a_{j,i}$.) Then, an eigenvector of the matrix is calculated for a maximum eigenvalue. The eigenvector is normalized so that the total sum of its elements is 1. The values of this eigenvector constitute the attribute weights.

	Economic	*Social*	*Political*	*Ideological*	*Technological*	*Eigenvector*
Economic	1	7	3	7	3	.45
Social	1/7	1	1/3	7	1/6	.09
Political	1/3	3	1	7	1/2	.17
Ideological	1/7	1/7	1/7	1	1/8	.03
Technological	1/3	6	2	8	1	.26

Figure 4. Matrix of attributes. (Saaty, 1982)

To determine the attribute scores for each alternative, a decision maker fills a matrix of pairwise comparisons between alternatives. Altogether, n matrices are filled (one for each attribute). The dimension of every matrix is the number of alternatives. Here, too, a normalized eigenvector is calculated and the elements of each such vector express the scores of the alternative for each attribute.

Pairwise comparisons are accomplished with a relative numerical scale. Saaty (1977), in agreement with G.A. Miller's 1956 experiments proving individuals cannot simultaneously compare more than seven objects (plus or minus two) at the same time without being confused, chose a numerical scale of 1 - 9. Using this scale, 1 expresses identity between two objects being compared and 9 expresses an absolute preference of one over the other. [Fig. 5]

The Eigenvector method enables one to examine a decision maker's consistency, using appropriate measures (in essence, if a decision maker is consistent in a certain matrix, the maximum eigenvector of the matrix equals the order of that matrix). On the other hand, this method ignores independence between attributes. It also does not consider risk and uncertainty. Nor does it enable one to perform sensitivity analyses. (Shoval and Lugasi, 1987)

The AHP removes the guess work from the assessment of the relative importance of various criteria. The AHP can assist in analyzing several variables simultaneously. A hierarchy is established so that sub-criteria relevant to a main criteria can be prioritized and comparisons can be made of minute details. (Saaty, 1980)

Intensity of Importance	*Definition*	*Explanation*
1	Equal importance of one element over another	Two elements contribute equally to the property
3	Weak importance of one element over another	Experience and judgment slighty favor one element over another
5	Essential or strong importance of one element over another	Experience and judgment strongly favor one element over another
7	Demonstrated importance of one element over another	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of the the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgments	Comprimise is needed between two judgments
Recirocals	If activity *i* has one of the preceeding numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Figure 5. Saaty's comparison table. (Saaty, 1982)

V. PROPOSED METHODOLOGY

Applying the AHP to Step 5 of Borovits and Zviran's methodology (Fig. 1) makes the resolution of ranking and weighting alternatives less arbitrary.

In selecting a computer-family, specific attributes, capabilities, and performance characteristics, collectively known as criteria, are used as the basis for comparison between the competing alternatives. In Step 5 of Borovits and Zviran's methodology, criteria are identified, prioritized and weighted according to their significance and value in the selection process. This procedure yields a maximum value for each criterion. Using the maximum values for all of the criteria, the highest possible score for each computer-family is computed. The maximum attainable scores in Step 5 are used in Step 7.

The AHP allows a decision maker to objectively create a prioritized and weighted list of criteria. At each level of the hierarchy, every criterion is compared to all the others in its group, on a one-to-one basis. Using the scale and descriptions from Figure 5, a score for each pairwise comparison is obtained. These scores are inserted into a matrix to compute the weight of each criterion by Saaty's eigenvalue method. The weight of each criterion is used with the weights of the criteria that are above it in the hierarchy to compute a maximum value.

To facilitate the incorporation of the AHP into Step 5 of Borovits and Zviran's methodology (Fig. 1), setting quantitative and qualitative criteria and respective weighting scales, the prioritization of all criteria is realized by completing six sub-steps.

The sub steps are listed below in the order they are to be accomplished.

5.1. - Prioritize the overall importance of qualitative versus quantitative criteria.

5.2. - Select applicable computer categories. Each category is evaluated separately.

5.3. - Select criteria for each computer category.

5.4. - Select sub-criteria for each criterion until there are no more sub-criteria.

5.5. - Prioritize and weight all categories, criteria, and sub-criteria.

5.6. - Calculate the absolute weights for all criteria and sub-criteria.

In Step 7, the process of receiving, comparing and analyzing bids is comprised of two sub-steps:

7.1. - Assign each relevant model of computer from a proposed computer-family to a category according to established criteria.

7.2. - Evaluate each computer-family in accordance with the criteria established in Step 5.

The advantage in applying the AHP to this methodology is that greater objectivity is achieved. No longer will an individual, or group, have to compare a large number of criteria and rank them, including the assignment of a relative value for each object. All comparisons are done one to one. The ranking and weighting of the criteria is computable and replicable.

Step 1. Identification of possible vendors and manufacturers.

Step 2. Primary elimination of irrelevant candidates.

Step 3. Determination of mandatory requirements.

Step 4. Examination of vendors' compliance with mandatory requirements.

Step 5. Setting quantitative and qualitative criteria and respective scales.

- **5.1.** Prioritize overall importance of qualitative and quantitative criteria.
- **5.2.** Select applicable computer categories. Each category is evaluated separately.
- **5.3.** Select criteria for each computer category
- **5.4.** Select sub-criteria for each criterion until there are no more sub-criteria.
- **5.5.** Prioritize and weight all categories, criteria and sub-criteria.
- **5.6.** Calculate the absolute weights for all criteria and sub-criteria.

Step 6. Writing the RFP to be addressed to selected vendors.

Step 7. Receiving, comparing, and analyzing bids.

- **7.1.** Assign each relevant model of computer from a proposed computer-family to a category according to predetermined criteria.
- **7.2.** Evaluate each computer-family in accordance with criteria established in Step 5.

Step 8. Drawing up a final list of vendors.

Step 9. Performance of hardware and software benchmarks.

Step 10. Drawing final conclusions and selection of best

Figure 6. Updated workflow diagram.

VI. DEVELOPING SELECTION CRITERIA AND SCALE

A. SELECTING AND PRIORITIZING CRITERIA

In order to select a computer-family that best fulfills its requirements, an organization must designate the qualities that will be used to compare the computer-families. These qualities, or characteristics, are called selection criteria.

Criteria that are used to evaluate computer-families are either quantifiable or non-quantifiable. The qualities that are not quantifiable are referred to as qualitative criteria and are evaluated subjectively. Those characteristics that are quantifiable and measurable by an established standard are called quantitative criteria, and are evaluated objectively.

Criteria used in the evaluation process will be placed at different levels in a hierarchy. At the top of the hierarchy is the "Total Evaluation of a Computer-Family". The second level consists of the division of qualitative and quantitative criteria. The next level is the first group of selectible criteria, in this case categories of computers.

At the lowest level are criteria that are elements of a criterion at the next higher level in the hierarchy. The criteria at each level, which are the descriptors of a criterion of the next higher level, are ranked in order of importance and scaled by their relative weight. This is the process of prioritizing.

The process of prioritization will be conducted using the Analytical Hierarchy Process developed by Saaty(1980). This uses a one to one comparison of all the items at the same level, producing a relative ranking and weighting of each criterion at that level in the hierarchy. These are the actions that take place during Step 5 [Fig. 6].

Step 5.1. Prioritize the overall importance of qualitative versus quantitative criteria. Because there are both qualitative and quantitative criteria used in the evaluation process, prioritization begins with the determination of the weights, or percentage of the total score, for each of these groups of criteria. This is a subjective decision made without the use of the AHP. It is the second level in the hierarchy.

Step 5.2. Select applicable computer categories. Each category is evaluated separately. Prioritization continues with the selection of the applicable computer categories for the computer-family and the determination of the relative weight of each category. Computer category is the third level in the hierarchy. The categories from which to choose are:

- Mainframe computer
- Super-minicomputer
- Minicomputer
- Super-microcomputer
- Microcomputer

Step 5.3. Select criteria for each computer category. For each computer category designated in Step 5.2, choose the appropriate main categories of criteria that can be used in the evaluation process. The main categories of criteria, taken from the list in Figure 2, are:

- Hardware
- Software
- Communication
- Conversion
- Environment

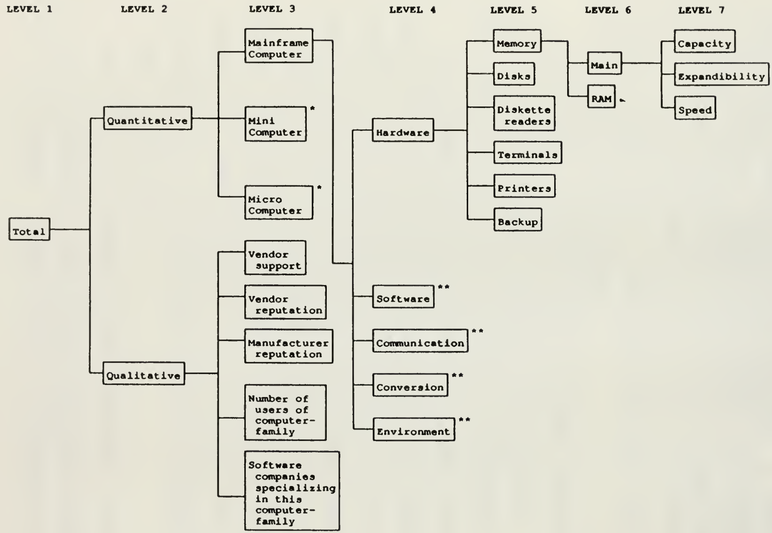
These categories of criteria are the fourth level in the hierarchy.

Step 5.4. Select sub-criteria for each criterion until there are no more sub-criteria. For each main category of criteria, Step 5.3, in each main category of computer, Step 5.2, select the appropriate sub-criteria. If a criterion can be further described by sub-criteria, continue the process of subdivision. Subdivision may occur down three, four or even five more levels.

In selecting the quantifiable criteria, care must be taken to select relevant items and to not continue subdividing a criterion just because it is possible to do so. The criteria selected should be for valid items of comparison so that when the evaluation of the computer-families is made, and there is a difference in score between computer-families, the difference is valid and meaningful.

A detailed list of quantitative criteria, which starts with the main categories of criteria at Level 4 in the hierarchy, is shown in Figure 8. For criterion that can be subdivided, the sub-criteria are listed in hierarchy Level 5, Level 6, and Level 7.

The qualitative criteria, even though they are evaluated much more subjectively, can also be prioritized using Saaty's procedures. A detailed list of qualitative criteria that may be used in comparison of computer-families is also shown in Figure 8. These criteria are at level 3 and level 4 in the qualitative side of the hierarchy. The hierarchy is shown in Figure 7.



* LEVEL 4 - LEVEL 7 are replicated for minicomputers and microcomputers.

** These categories are further broken down in LEVEL 5 - LEVEL 7 with criteria from Figure 2 and are listed in Appendix B.

Figure 7. Hierarchy of criteria.

Level 4	Level 5	Level 6	Level 7
Hardware			
	Memory		
		Main	
			Capacity
			Expandability
			Speed
		RAM	
			Capacity
			Expandability
	Disks		
		Number of drives	
		Capacity	
	Diskette Readers		
		Size	
		Number	
		Density	
	Terminals		
		Monitors	
			Monochrome
			Color
			Graphics abilities (CGA,EGA,VGA)
		Keyboards	
		Voice	
	Printers		
		Color	
		Graphics	
		Laser	
		Size	
	Backup		
		Size	
		Speed	

Figure 8.1. Detailed List of Criteria, Hardware

Level 4	Level 5	Level 6
Software		
	System software	
		Operating system uniformity
		Utilities
		Compilers
		Compatibility
		Ability to modify
		Documentation
	Programming languages	
		Compilers
		Interpreters
		Adherence to standards
		Options and extensions
	Development tools	
		Application generators
		Report generators
		Full screen editors
		Debugging aids
		Macro facilities
	Additional software	
		Word processors
		Spreadsheets
		Database Management Systems
		E-Mail
	Software transferability	

Figure 8.2. Detailed List of Criteria, Software

Level 4	Level 5	Level 6
Communication		
	Communication protocols	
	Local area networks	
		Capacity (Number of terminals)
		Maximum distance
		Transmission medium
		Speed
	Wide area networks	
		Transmission medium
		Internet capability
Conversion		
	Integration of current programs	
	Integration of data files	
Environment		
	New building requirements	
	Special conditions	
		Temperature
		Humidity

Figure 8.3. Detailed List of Criteria, Communication, Conversion, and Environment.

Level 3	Level 4
Vendor Support	
	Training
	Maintenance
	Philosophy
	Practice
Vendor's reputation	
	User opinion
	Trade journal evaluations
Manufacturer's reputation	
	User opinion
	Trade journal evaluation
Number of users of computer-family	
Software companies specializing in this computer-family	

Figure 8.4. Detailed List of Qualitative Criteria

Step 5.5. Prioritize and weight all categories, criteria and sub-criteria. For each category of computer, the appropriate criteria and sub-criteria are listed. After all the criteria are listed, they, along with the computer categories are prioritized and weighted using Saaty's eigenvector method. [Fig. 9]

As described earlier, Saaty's method requires a pairwise comparison of those criteria that are located at the same level in the hierarchy. Every criterion being compared is rated against every other criterion in the same group. A value is obtained, based on the values from Figure 5, and inserted into the matrix. The size of the matrix should be limited to 7 +/- 2 items (Saaty, 1982). The matrix generates a relative weight that is given to each category or criterion. This is an eigenvector; it has a decimal value or percentage of 1. The total value of all the weights generated for each group being compared is 1 or 100%.

B. PRIORITIZING AND WEIGHTING: A DETAILED EXAMPLE

After prioritizing the collective qualitative and quantitative criteria, Step 5.1, and then selecting the applicable computer categories and appropriate criteria and sub-criteria, Steps 5.2 - 5.4, a decision maker is ready to begin computing priorities.

In this example, three categories of computers, selected in Step 5.2, are placed in a matrix [Fig 9]. The three categories selected are Mainframe computer, Minicomputer, and Microcomputer. To determine the relative weight for each category, a decision maker has to compare each category to the other two categories, one at a time, and select the number 1 to 9 which best represents the intensity of importance of one category to the other. The scale, shown in full in Figure 5, is presented here, in its abbreviated form.

Intensity of Importance	Definition
1	Equal importance.
3	Weak importance of one over another.
5	Essential or strong importance.
7	Demonstrated importance.
9	Absolute importance.
2,4,6,8	Intermediate values between the two adjacent judgments.

The numbers that are inserted into the matrix compare the item on the left with the item in the top row and represent the value from the scale above. If the item on the top is considered more important than the item on the left, a fraction, the reciprocal value of the comparison, is entered into the matrix.

Sample values have been entered into the matrix. [Fig. 9.1] Using the sample values an eigenvector will be computed for each computer category. The eigenvector will be used as the relative weight of the computer category.

Hierarchy Level 3

Computer Category	Main-frame	Mini	Micro
Mainframe	1	5	3
Mini	1/5	1	1/4
Micro	1/3	4	1

Figure 9.1 The Initial Matrix

The matrix is then normalized by adding the values in each column, then dividing each entry in each column by the total of that column. A new matrix with normalized values is created. [Fig. 9.2]

Computer Category	Main Frame	Mini	Micro
Mainframe	1	5	3
Mini	1/5	1	1/4
Micro	1/3	4	1
	-----	--	----
Column total	1.533	10	4.25

↓

Computer Category	Main Frame	Mini	Micro
Mainframe	0.652	0.500	0.706
Mini	0.131	0.100	0.059
Micro	0.217	0.400	0.235

Figure 9.2 The Normalized Matrix

The last step is to average over the rows by adding the values in each row of the normalized matrix and dividing the rows by the number of entries in each. This number is the eigenvalue and is the weight that is given to that category. [Fig. 9.3]

		Computed Relative Weight
Mainframe	$\frac{.652 + .500 + .706}{3} =$	.6193
Mini	$\frac{.131 + .100 + .059}{3} =$	.0967
Micro	$\frac{.217 + .400 + .235}{3} =$	.2840

		1.0000

Figure 9.3 Computing the Eigenvalue

The total relative weight for all computer categories is equal to 1 or 100%.

Consistency of the values must be taken into account in computing the eigenvectors using the calculated consistency index (CI), dividing the CI by the random value of consistency from a table. The random value is dependent on the number of items in the matrix. The resultant is the consistency ratio (CR). The CR should be 10% or less, indicating judgments in comparing items in the matrix were not randomly made. (Saaty, 1982)

The matrices listed in Appendix A have listed in them criteria and sub-criteria from hierarchy Level 4 down through Level 7. For this example, only the first criterion from the previous level will have its sub-criteria listed in the next lower level. The numbers along the top row of each matrix refer to the corresponding numbered item on the left side of the matrix. The weight, in the last column, is the relative weight, the eigenvalue, of the criterion named in that row, in the left column.

For this example, the Mainframe Computer category is used. Its relative weight has already been calculated. [Fig.9.3] The main categories of criteria are selected, and relative weights are computed for each of these criteria. The first matrix determines the relative weights a decision maker places on each of the main categories of criteria for each of the computer categories. The decisions made here have an effect on the importance of the decisions made lower in the hierarchy. For example, if hardware turns out to be worth 75% in the evaluation of minicomputers, the remaining categories of criteria are worth only 25%, no matter how many sub-criteria are used in the evaluation process. This is another reason not to subdivide criteria unnecessarily.

Step 5.6. Calculate the absolute weights for all criteria and sub-criteria. Following the method proposed by Borovits and Zviran (1987), a scoring system that makes 100 points the maximum score attainable for a computer-family, will be used in conjunction with the AHP.

The absolute weight for a criterion is computed by multiplying its relative weight by the relative weight of each of its predecessors in the hierarchy [Fig. 10], or by the absolute weight of its immediate predecessor. When a computer-family is evaluated the maximum score available for any criterion is its absolute weight. A list of absolute weights will be shown on an evaluation sheet, Appendix B used in conjunction with the scoring of the competing computer-families, in Step 7.

An example of how an absolute weight is calculated is shown in Figure 10. A sample value is used for the relative weight of quantitative criteria. The relative weight for computer categories, mainframe computer was computed in Figure 9.

The process is demonstrated in Figure 10 and is completed for each criterion in the hierarchy of a computer-family. The absolute weight for the criteria whose relative weights were calculated in Appendix A are shown on the Vendor Evaluation Form in Appendix B.

Computer-Family Total Weight	Quantitative Criteria Relative Weight	Mainframe Computer Relative Weight
= 1.00	= 0.80	= 0.6913

Absolute Weight for Mainframe Computer =
(1.00) x (0.80) x (0.6913) = 0.4954

Figure 10. Computing an absolute weight of a criterion

VII. THE EVALUATION PROCESS

After the process of prioritizing the criteria has been completed, the process of evaluating each of the competing computer-families begins. In Borovits and Zviran's (1987) methodology this is accomplished as part of Step 7.

In response to the request for proposal (RFP) that was sent out to vendors, bids for proposed computer-families will have been received. These bids then have to be analyzed and evaluated with scores assigned. In Steps 8, 9, and 10, the highest rated computer-families, on the basis of score, are selected for further evaluation and testing and, ultimately, one will be selected as the winner.

The scope of Step 7 is the initial evaluation and scoring of the proposed computer-families, submitted in response to the RFP. As stated previously, this is completed by two sub-steps.

Step 7.1. Assign each relevant model from a proposed computer-family to a category, according to predetermined criteria. In Step 5.2, computer categories were selected. The decision maker chose the computer categories that met an organization's needs. Each relevant computer model from the proposed family will be placed in the appropriate computer category and will be evaluated by the criteria already selected for that category.

The determination as to which category a computer will be placed is based on, but not limited to, such factors as CPU, memory or disk drives. The decision as to what factors will constitute placement into a particular category will have been determined when the categories were selected in Step 5.2.

Step 7.2. Evaluate each computer-family in accordance with the criteria established in Step 5. Using the evaluation form, Appendix B, each computer-family is evaluated, criterion by criterion, with the result posted on the form. The total for the computer-family is then computed and a final score is established.

The maximum score possible for any criterion is its absolute weight. The score assigned and posted on the form is on a scale of 0-1. Complying with the criterion completely is scored as 1, anything less is a decimal value less than 1. The posted score is multiplied by the absolute weight to yield the absolute score for that criterion. All of the absolute scores are added to yield the final score for the computer-family. Only the lowest level criteria are scored. The maximum total score is 100. When this process has been completed for each of the computer-families, an objective comparison based on the final score may be made. The three or four highest rated computer-families may then be evaluated further by operational and benchmark testing.

In Appendix B, the relative weights computed in Appendix A have been inserted into the evaluation sheet. Using those relative weights, the absolute weights for all criteria cited in the example have been computed.

VIII. CONCLUSION

The process of selecting a computer-family is a complex procedure. The goal for a decision maker, responsible for selecting a computer-family, is to select the correct line of products for an organization. Because of the complexity of the selection process, a formalized methodology makes the process more objective.

Using the methodology presented here, along with methodology developed by Borovits and Zviran (1987), an objective selection process is created. The process allows the designation of appropriate criteria to be used in the selection of a computer-family. The appropriate criteria are those selected by an organization trying to select a computer-family, based on an evaluation of its needs.

Once criteria have been selected, they are objectively prioritized and weighted, establishing their net value and absolute weight in an overall evaluation of a computer-family. Each computer-family is evaluated and scored separately, but in accordance with the prioritized and weighted criteria.

In spite of the careful process of prioritizing and weighting, total objectivity can not be achieved. Individuals comparing criteria will still be making subjective judgments as to the relative importance of one criterion versus another. This cannot be avoided.

Subjectivity in the comparison of criteria may be counteracted by checking for consistency. The ability to measure the consistency in the comparison of criteria adds a check and balance to the process not previously present.

By following the procedures developed in this thesis, the process of selecting a computer-family is made reliable and objective. The end product of this process, a computer-family that best meets the needs of an organization, may be chosen with the knowledge that the correct computer-family was selected.

APPENDIX A

Sample values, using the guidelines from Figure 5, have been inserted into the matrices. Using the process in Step 5.5, each matrix was normalized. The relative weight listed in the last column is the eigenvalue of the criterion in the first column in that same row.

Level 3

Computer Category	1	2	3	Relative Weight
1.Mainframe	1	5	3	0.6193
2.Mini	1/5	1	1/4	0.0964
3.Micro	1/3	4	1	0.2842

				1.0000

Level 4

Main Categories of Criteria (Mainframe)	1	2	3	4	5	Relative Weight
1.Hardware	1	1/2	5	3	6	0.3024
2.Software	2	1	5	3	7	0.4119
3.Communication	1/5	1/5	1	1/4	3	0.0775
4.Conversion	1/3	1/3	4	1	4	0.1656
5.Environment	1/6	1/7	1/3	1/4	1	0.0426

						1.0000

Level 5

Hardware	1	2	3	4	5	6	Relative Weight
1.Memory	1	3	6	2	5	4	0.3633
2.Disks	1/3	1	3	1/3	3	5	0.1663
3.Diskette Readers	1/6	1/3	1	1/5	1/3	1/3	0.0420
4.Terminals	1/2	3	5	1	3	5	0.2631
5.Printers	1/5	1/3	3	1/3	1	3	0.0986
6.Backup	1/4	1/5	3	1/5	1/3	1	0.0667
							1.0000

Level 6

Memory	1	2	Relative Weight
1.Main	1	1/3	0.25
2.RAM	3	1	0.75
			1.00

Level 7

Main Memory	1	2	3	Relative Weight
1.Capacity	1	1/2	1/3	0.1593
2.Expandibility	2	1	1/3	0.2518
3.Speed	3	3	1	0.5889
				1.0000

RAM	1	2	Relative Weight
1.Capacity	1	1/4	0.2
2.Expandibility	4	1	0.8

APPENDIX B

Vendor Evaluation Sheet	Relative Weight	Absolute Weight	Score	Absolute Score
Total	1.000	1.000		
Quantitative	.8000	.8000		
Mainframe	.6193	.4954		
Hardware	.3024	.1498		
Memory	.3633	.0544		
Main	.2500	.0136		
Capacity	.1593	.0022		
Expandibility	.2518	.0034		
Speed	.5889	.0080		
RAM	.7500	.0408		
Capacity	.2000	.0082		
Expandibility	.8000	.0326		
Disks	.1663	.0249		
Number of drives				
Capacity				
Diskette Readers	.0420	.0063		
Size				
Number				
Density				

Vendor Evaluation Sheet
Mainframe Hardware (cont'd)

	Relative Weight	Absolute Weight	Score	Absolute Score
Terminals	.2631	.0394		
Monitors				
Monochrome				
Color				
Graphics abilities				
Keyboards				
Voice				
Printers	.0986	.0148		
Color				
Graphics				
Laser				
Size				
Backup	.0667	.0010		
Size				
Speed				
Software	.4119	.2041		
System software				
Op. system uniformity				
Utilities				
Compilers				
Compatibility				
Ability to modify				
Documentation				

Vendor Evaluation Sheet
Mainframe Software (cont'd)

	Relative Weight	Absolute Weight	Score	Absolute Score
Programming languages				
Compilers				
Interpreters				
Adherence to standards				
Options and extensions				
Development tools				
Application generators				
Report generators				
Full screen editors				
Debugging aids				
Macro facilities				
Additional software				
Word processors				
Spreadsheets				
Database mgmt. systems				
E-Mail				
Software transferability				

Vendor Evaluation Sheet
Mainframe (cont'd)

	Relative Weight	Absolute Weight	Score	Absolute Score
Communication	.0775	.0384		
Communication protocols				
Local area networks				
Capacity (# of terminals)				
Maximum distance				
Transmission medium				
Speed				
Wide area networks				
Transmission medium				
Internet capability				
Conversion	.1656	.0821		
Integrate current progms.				
Integration of data files				
Environment	.0426	.0211		
New building requirements				
Special Conditions				
Temperature				
Humidity				

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Thesis
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c.1 Developing a comprehensive methodology for computer-family selection.