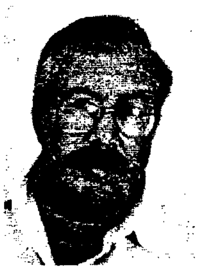
# Designing a multi-micro distributed accounting information system

A. ARBEL and
A. SEIDMANN *
*Tel-Aviv University, Faculty of Engineering, Department of Industrial Engineering, Tel-Aviv 69978, ISRAEL*



**Ami Arbel** is a senior lecturer at the Department of Industrial Engineering, Tel-Aviv University, Tel-Aviv, Israel. He received a BSME from the Technion, I.I.T., Israel, an MSME from UC Berkeley, and an MS and a PhD degree from the Engineering Economic Systems department at Stanford University. Prior to joining the Tel-Aviv University, Dr. Arbel was a Senior Research Engineer with Engineering Consulting Companies in the U.S., consulting in areas of systems theory, optimization methods, decision analysis and strategic studies. He is member of TIMS & IEEE.

**Abraham Seidmann** is a lecturer at the Department of Industrial Engineering of Tel-Aviv University. He holds BSc and MSc degrees from the Technion, Israel Institute of Technology, and a PhD in industrial engineering from Texas Tech. University, Dr. Seidmann's research interests include computerized production systems, microcomputers in operational systems, and production management. He has published in these areas in such journals as The International Journal of Production Research, Management Science, IEEE SMC and Operations Research. He is senior member of IIE and a member of TIMS, ACM and Alpha Pi Mu.

The problem of evaluating and selecting a distributed multi-micro or mini-based information system is presented. These systems are characterized by various hardware and software factors, and the selection process is aimed at satisfying pertinent functional requirements. This paper presents a new model based on the Analytic Hierarchy Process that provides the framework for assessing this multicriteria decision problem.

The model provides methodological guidelines considering a wide range of needs such as performance levels, system expandability, data confidentiality and integrity, as well as several other nontechnical or intangible factors.

*Keywords:* Microcomputer selection, analytic hierarchy process (AHP), multi-attribute decision models.

* The authors would like to thank P. Ein-Dor and N. Ahituv from the Faculty of Management at Tel-Aviv University for useful discussions and comments.

North-Holland
Human Systems Management 5 (1985) 283–291



## 1. Introduction

In the last few years distributed processing has come to the forefront of information systems design. When computers were first introduced organizations had little alternative to installing centralized systems. Recent improvements in the price/performance ratio of processors and memories, has led to microcomputer business systems which can operate as stand-alone or as nodes in distributed systems. These developments have resulted in new viable information processing and decision aids [11,18,22]. The benefits offered by the introduction of distributed processing present management with considerable decision problems regarding the selection of advanced technological systems that best suit specific organizational needs and services to be provided.

The selection problem is particularly acute when many units have to be installed and operate in concert, and when none of the systems under consideration exhibits a clear dominance over its competitors. When one system emphasizes technological (hardware) capabilities, another emphasizes software performance, and yet a third may emphasize service and reliability, one should not judge the relative importance of those factors by measures devoid of projected needs [22,26].

The installation of a distributed system is likely to involve new hardware and unfamiliar software. Many acquisitions, therefore, are directed at off-the-shelf systems (as opposed to a custom design at an increased cost), where the complete installation is backed by a single vendor. In these cases one has to evaluate several distinct configurations proposed by various vendors [19]. While the direct acquisition costs of the single microcomputer system may not be excessive – the cost of a distributed system comprised of many units may present a considerable investment [6,24]. Systematic selection methodologies should, therefore, be developed and applied to these selection problems.

Selecting equipment to satisfy the information processing needs requires a trade-off between hardware performance and software availability [5,9,24]. Early studies treating the selection procedures of computers, pointed to the measurements of the average execution time for several mixes of instructions as a good indicator of the central processor speed [20]. More recent research pointed out to other methods such as standard benchmark (sample) problems [2], analytic workload models and simulation techniques [4], [16]. These methods can predict the anticipated system productivity over a wide range of workload parameters. In order to define performance some attempts at formal, functional, analysis of information systems have also been made [1]. Various arbitrary scaling or weighted factor methods are used in computing a composite scale for several computer system parameters [10]. Other authors center on providing checklists and questionnaires as aids for the evaluation process [9,20]. Organizational models treating the selection problem in the context of corporate planning are discussed in [13]. This paper describes a decision framework for selecting a micro-based distributed information system [3], [7]. The analysis is concerned with the selection problem only and takes the decision to adopt a network of microcomputers as given.

The selection procedure is based on the Analytic Hierarchy Process (AHP) developed by T.L. Saaty [15,17,23]. This particular methodology is used because one is basically interested in a *value* assessment of the deterministic decision factors involved rather than a *utility* assessment. The latter can be provided, of course, through the multiattribute utility approach which accounts for risk attitude in decisions under uncertainty [17].

Section 2 outlines the general structure of the evaluation and selection model. Section 3 presents an illustrative assessment example of deriving priorities and consistency validations. Finally, sections 4 and 5 present sensitivity analysis and conclusions.

## 2. The design and evaluation model

In the design of distributed information systems one can distribute the data files, the processing power and the communication capabilities. In many cases, the distributed system operates with a minimal support from a central processor or a communication controller. A typical example is the case of a system composed of several microcomputers all connected in a local area network (LAN) with disjoint memory address spaces. In this paper we address such a system where each node of the system is a work-station serving an accounting and other financial-related information systems. Each work-station has full capability for stand-alone operability including files management and hard-copy productions. In addition, it has the ability to communicate messages, queries and files with other work-stations. The system design can be based on a standard LAN communication protocol such as Newhall-type or sloted rings schemes [22]. The design process of such a system starts with a conceptual evaluation of the desired file strategy, work flow method determination and a communication network selection.

The major capital investment – and thus the major decision problem – is the determination of the data communication network and the appropriate microcomputer systems for the distributed work stations.

An important problem in the evaluation of distributed systems is the identification and the assessment of tangible and intangible factors affecting their overall performance. These include such issues as software capability versus hardware performance, vendor's reputation, specific application needs and information integrity, to name a few. These systems can be characterized by a number of parameters describing performance levels and requirements for these systems. These parameters make up a detailed checklist that prospective buyers should follow in arriving at an acquisition decision [7,9,19]. Such a list is provided in table 1, showing parameters relevant to several applications. Specific applications may require deletion and, in some cases, additions to this list as deemed necessary. Table 1 provides many of the parameters deemed relevant to a particular accounting information system. For more details with respect to the individual workstation parameters please consult [18]. A major aspect of the

Table 1
Common distributed information systems parameters.

| |
|---|
| *Network management* |
| Status monitoring |
| Authorizations |
| Online reconfigurations |
| Distribution of controls |
| Polling lists |
| *Vendor's support* |
| – Technical trouble-shooting |
| – General reputation |
| – ... |
| – ... |
| *CPU and main memory* |
| – Word size |
| – Operating system |
| – Memory size |
| – ... |
| – ... |
| *Local storage* |
| – Capacity |
| – Average access time |
| – ... |
| – ... |
| *VDU* |
| – Resolution |
| – Dimensions |
| – Glare |
| *Application packages* |
| – Operational fit |
| – Storage versatility |
| – Required memory |
| – Statistical recording |
| *Protocols and Architecture* |
| – Electrical interface |
| – DLC |
| – Error handling |
| – Message coding |
| – Bootstrapping |
| – Interconnections |
| – Line utilization |
| *Dynamic controls* |
| – Priorities |
| – Congestion controls |
| – Diagnostics |
| – Routing |
| – Deadlock avoidance |
| *Physical design* |
| – Topology |
| – Modems |
| – Node memory |
| – Line speeds |
| – Type of carrier |
| – Concentrators |

paper is concerned not merely with the relevancy of parameters to a particular setting but with their priority.

The priority structure derived in this paper may identify parameters that while being relevant, are of low priority. This point is elaborated in latter parts of the paper.

Using the list of parameters shown in table 1, a request for proposal (RFP) is issued to prospective vendors. The RFP specifies minimal requirements to be met by the proposed systems. For example, minimal capacity of the main memory at each station and the size and nature of storage facilities. The first group of parameters is influenced by the size of records to be manipulated while the second group of parameters is influenced by the size of files and the speed by which they should be retrieved from the local storage facility. Other minimal requirements may specify such attributes as printing speed/quality, data channels and the bus interface unit (BIU). Once proposals are received they undergo a prescreening phase after which a few proposals will enter the final evaluation phase.

Note, however, that the appearance of the various parameters in table 1 does not indicate that they are all of equal importance to the overall selection. The relative importance associated with each element of table 1 is dependent on the performance criteria it supports and may shift, from one category to another. These criteria include the *throughput* or *response time* measures, *data security*, *communication integrity*, *interconnection capabilities* and *growth potential*. These performance criteria may be partitioned into various subsets. In this case, for example, the communication integrity is partitioned into *availability* and *recovery* subcriteria. These performance criteria support two major system functions which determine the design evaluation process. They refer to the *operators* and to the *distributed processing* system functions. The relative importance of the performance criteria is affected by the specific needs for an information system. Therefore, one has first to *identify* and *prioritize* the specific system functions to be supported by the new system. Only then, can one prioritize all the performance criteria and the system parameters which are listed in table 1, based on their contributions to the various performance criteria. After these selection parameters have been prioritized, a systematic comparison of candidate systems can be made leading to the selection of a system which dominates all the others. This model in its aggregate form is shown in fig. 1.

To summarize, the first level in the hierarchical model displays the *system functions*. It is partitioned into two basic sets of functions. The *operator's* functions include three major subsets; the first subset is the operational savings which stem from direct time savings and reduced clerical effort; the second subset includes improved customer service due to better reporting timeliness, enhanced account monitoring and report quality; the third subset focuses on user-friendliness and ease of operation. The user's consideration and human factors engineering (ergonomics) refer to both hardware and software aspects. The electronic data processing elements of data collection, communication, manipulation, reduction, file storage etc. are all included in the second set of system functions. These *distributed processing* functions cater to data transmission (remote and local), master-files update, the generation of periodic reports, file design, online transaction processing along with augmented processing power.

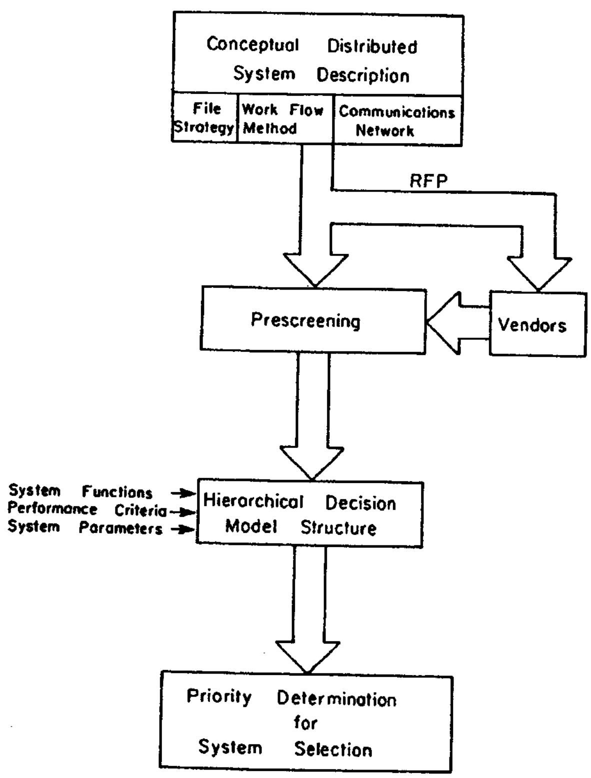



Fig. 1. The system design process.

Next, at the second level of the hierarchical model, *performance criteria* are separated into specific groups. These criteria, used in describing the attainment of the system functions, are evaluated based on the *system parameters* appearing on the third level of the hierarchy. The complete model is shown in fig. 2. This model describes many factors, some of which may not be relevant in certain situations. This modelling approach allows the deletion, and in some instances even the addition, of elements to certain levels identified in the evaluation hierarchy. It results in a flexible approach capable of handling various environments and needs.

The next section applies the Analytic Hierarchy Process (AHP) to the model developed in this section and provides a numerical illustration of the assessment and selection process for a specific case.

## 3. An illustrative example

This section applies the model developed in the previous section to a specific acquisition case posed by several competing designs. Rather than providing a complete detailed account of the decision process, the presentation in this section will merely highlight the details. At this stage of the analysis it is assumed that the basic requirements of the data communication network, the system architecture and the workstations have been determined and one has to select the most appropriate system for the distributed processing application.

In order to prioritize the selection parameters of table 1, one has to consider the complete model described in fig. 2 and prioritize all its elements. The prioritization of the model's elements is carried out through the 'Analytic Hierarchy Process' developed by T.L. Saaty [15]. This methodology requires that, first, one has to prioritize the system functions. This results in a set of priorities reflecting the importance of each of the functions in the selection process. This process is repeated for each following level by first assessing local priorities of members of the $i$th level with respect to each member of the $(i\text{-}1)$th level. Then, weighting these priorities by the priority of the element in the $(i\text{-}1)$th level, one converts these *local* weight to *global* weights and proceeds down the hierarchy until the bottom level is reached, at which stage

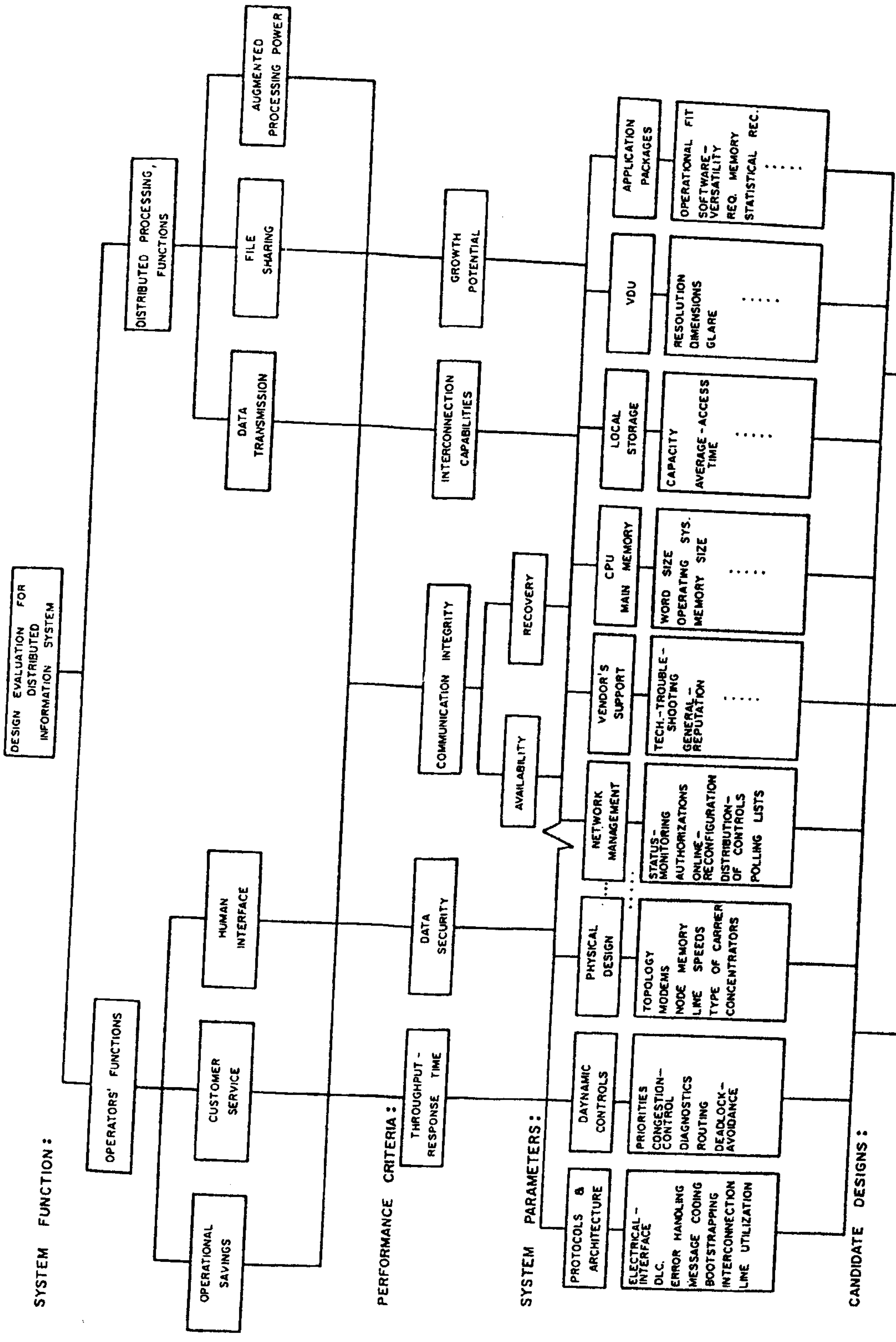



Fig. 2. Hierarchical structure for distributed information system design.

the specific candidate systems are prioritized.

Let us denote by $W(i+1, i)$ the matrix of *local* weights relating level $(i+1)$ to level $i$. That is, each column of this matrix, say $w_j$, provides the local weights of element in level $(i+1)$ with respect to the $j$th element in levelcr $i$. The *global* priorities of elements in level $(i+1)$ are given, therefore, by

$$p(i+1) = W(i+1,i)p(i), \tag{1}$$

where $p(i)$ is the vector of global priorities of elements in level $i$. If the hierarchy has $n$ levels, then the global priorities of elements in the $n$th level are given by

$$p(n) = W(n,n-1)W(n-1,n-2) \ldots W(2,1)p(1) = W(n,1)p(1), \tag{2}$$

where

$$W(n,1) = W(n,n-1)W(n-1,n-2) \ldots W(2,1). \tag{3}$$

As outlined above, the first step is concerned with the assessment of importance of the system functions. This is done by asking $n(n-1)/2$ (in this case $n=2$) pairwise comparison questions of the type 'which of the following two functions dominates the other, and by how much?' The first part of the question is clearly an ordinal question while the second part is a cardinal one requiring a numerical input. This input is provided by using the ratio scale described in table 2. (for a detailed discussion of the scale and related topics please consult [15].)

The assessment of the relative importance of the two system functions is straightforward and, therefore, is omitted; the first assessment to be illustrated by a comparison matrix is carried out for the three subdivisions of the distributed processing functions. These assessments are summarized in table 3.

The data shown in table 3 comprises the *comparison matrix*, $A$. The information displayed in this matrix is interpreted as follows; every element $a_{ij}$, of the matrix $A$ shows the relative contribution – to the subject of comparison – of the $i$th activity as compared to the $j$th activity, i.e.,

$$a_{ij} = w_i/w_j, \quad 1 \le i \le n, \quad 1 \le j \le n. \tag{4}$$

The actual entries are derived by using the scale described in table 2.

Note that the matrix $A$ is a *reciprocal* matrix, i.e., $a_{ij} = 1/a_{ji}$. Therefore, whenever the $ij$th element of the matrix is specified, the $ji$th position is automatically determined by its reciprocal value. To actually recover the weights, $w_i$, rather than their ratios we proceed as follows. Note that the matrix $A$ in table 3 is of unity rank and, therefore. $(n-1)$ (where $n=3$ in this case) of its eigenvalues $(\lambda_i)$ are equal to zero, besides

$$\sum_{i=1}^{n} \lambda_i = \text{trace}(A) \triangleq \sum_{i=1}^{n} a_{ii} = n, \tag{5}$$

and therefore the single nonzero eigenvalue is equal to $n$. It is easily verified that $Aw = nw$ from which follows that $w$ is the (normalized) eigenvector associated with the largest eigenvalue of the matrix $A$ in Table 3. The case shown in (4) represents the perfectly consistent case where $a_{ij} = a_{ik}a_{kj}$, $\forall\ i, j, k$. Recall that the elements of the matrix $A$ in table 3 are estimated through the use of the scale whose values are given in table 2. In general the elements (4) satisfy $a_{ij} = w_i/w_j + \epsilon_{ij}$ where $\epsilon_{ij}$ is some error that represents inconsistencies in judgement and then $a_{ij} \ne a_{ik}a_{kj}$. It can be shown that the largest eigenvalue of the matrix $A$, $\lambda_{max}$, satisfies $\lambda_{max} \ge n$ where equality holds for the

Table 2
Comparison scale.

| Intensity of importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance of one over another |
| 5 | Essential or strong importance |
| 7 | Very strong or demonstrated importance |
| 9 | Absolute importance |
| 2,4,6,8 | Intermediate values between adjacent scale values |

Table 3
Distributed processing functions.

| Sub-functions | (1) | (2) | (3) | Priority |
|---|---|---|---|---|
| (1) Data transmission | 1 | 5 | 7 | 0.731 |
| (2) File sharing | 1/5 | 1 | 3 | 0.188 |
| (3) Augmented processing power | 1/7 | 1/3 | 1 | 0.081 |
| $\lambda_{max} = 3.0649$; $C.I. = 0.0325$; $C.R = 0.0559$ | | | | 1.000 |

perfectly consistent case only. A *consistency index* is now defined as

$$C.I. = (\lambda_{max} - n)/(n-1), \tag{6}$$

which is zero in the perfectly consistent case. To assess the consistency derived in (6) we compare it to the worst case which will be the case of a pairwise comparison matrix whose entries are filled at random. Doing it for many samples and for various matrices, Saaty [15] has obtained the following:

| $n$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $R.I.$ | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | (7) |

where $n$ represents the dimension of the matrix and $R.I.$ is the *random index* evaluated through (6) for these random matrices. Now one defines the *consistency ratio* $(C.R)$ as

$$C.R. = C.I./R.I., \tag{8}$$

which is required to be less than 0.1 for acceptable results (more on this is found in [15]). Table 3 provides, in addition to the comparison matrix, the vector of priorities, and the consistency ratio. Fig. 3 displays these priorities.

Deriving the local priorities of the system subfunctions with respect to their 'host' functions (cf. table 3) and weighting them by the priorities of the 'host' function yields the global priorities of all the (specific) system subfunctions. These are given in table 4 assuming that the priorities assigned to the operators functions is 0.25 and that for the distributed processing is 0.75.

Now that the global priorities of all the elements in the system functions have been established, we proceed to level 2 that describes the performance criteria. Not all the elements listed in this level are relevant elements in each case. For example, in considering contributions to the 'file sharing' category, only 'data security', 'communications integrity', 'interconnection capabilities' and 'growth potential' are relevant. The reason is that the system design applied here calls for local validation of the financial records at each workstation. This was done in order to provide effective means of record lock-out and to ensure standalong operability. Only four performance criteria were, therefore, considered relevant to the 'file sharing' function (cf. table 5). Other performance criteria such as response time are clearly relevant in other cases considering customer service or in judging the 'human interface'. As a rule, the relevancy of the various criteria to specific subsets of the system functions is not fixed and it varies from installation to installation.

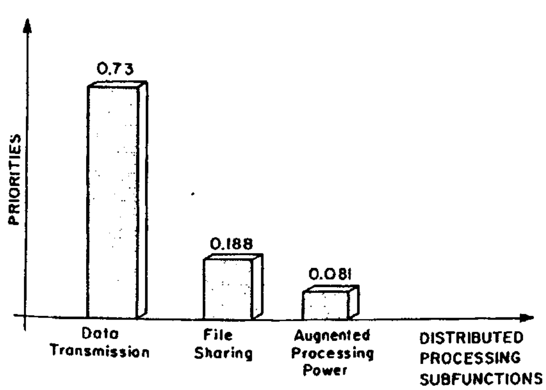



Fig. 3. The priorities of the distributed processing subfunctions.

Table 4
Global priorities of system functions.

| Category | Global priority |
|---|---|
| Operational savings | 0.111 |
| Customer service | 0.042 |
| Human interface | 0.097 |
| Data transmission | 0.548 |
| File sharing | 0.141 |
| Augmented processing power | 0.061 |
| Total | 1.000 |

The assessment of the importance of these criteria to the 'file sharing' category is summarized in table 5.

This process is repeated for each of the performance criteria and its relevant attributes. Once the local priorities with respect to each of the system functions are derived, we weigh these by the respective global priorities of the system functions as derived in table 4 to obtain the global priorities of the performance criteria. These global priorities are summarized in tabel 6.

Following the previous scheme of first computing the local priorities from the pairwise comparison matrices and then using the hierarchial composition to derive the global priorities, the assessment process continues to the next levels of system parameters. Each of these 'system parameters' is actually comprised of a number of more specific

Table 5
Criteria with respect to 'file sharing'.

| Criteria | (1) | (2) | (3) | (4) | Priorities |
|---|---|---|---|---|---|
| (1) Data security | 1 | 1 | 1/3 | 3 | 0.216 |
| (2) Communication integrity | 1 | 1 | 1/2 | 2 | 0.211 |
| (3) Interconnection capabilities | 3 | 1/2 | 1 | 4 | 0.476 |
| (4) Growth potential | 1/3 | 1/2 | 1/4 | 1 | 0.097 |
| $C.R.=0.023$ | | | | | 1.000 |

Table 6
Global priorities of performance criteria.

| Criteria | Priority |
|---|---|
| Throughout/Response time | 0.254 |
| Data security | 0.251 |
| Communication integrity | 0.112 |
| Interconnection capabilities | 0.069 |
| Growth potential | 0.314 |
| Total | 1.000 |

items. For example, 'physical design' is comprised of: (network) topology, modems, node memory, line speeds, type of carrier and the concentrators. Evaluating the relative importance of these parameters leads to the comparison matrix shown in table 7.

The last column is obtained by multiplying the local priorities with the global priority of physical design (0.215).

Again, we repeat this process for all the elements of the 'system parameters' level until the global priorities for all the elements appearing in table 1 are derived. This step is skipped for brevity.

Now, finally, one is in a position to directly assess the priorities of the three candidate systems. This is done by comparing the three systems relative to each of their systems parameters. It is known, for example, that the three candidate systems A, B and C had line speeds of 2400, 4800 and 2400 bauds, respectively. In comparing these systems relative to 'line speeds' table 8 is obtained.

Note that the entries in the matrix were not taken as simply the ratio between the respective line speeds (2400 vs. 4800 bauds) but rather, the 4800 bauds lines were judged by the technical experts to be of moderate dominance relative to the 2400 baud lines (the entry 3 corresponds to a scale value of 'moderate importance' in table 2).

Repeating this process of comparing the three systems relative to all parameters and weighting their local priorities by the global priorities of the parameters yields the global priorities for these systems.

The system to be selected is, of course, that having the highest global priority. The final conclusion in favor of a given system is reached based on subjective input reflecting the importance of the system functions shown at the top level of hierarchy in fig. 2 in a specific environment. A different setting may result in the same systems being perceived in quite a different way. Should a slight shift in the priorities of the system functions alter our decision? Referring to (2) one notes that

Table 7
'Physical design' attributes.

| Attributes | (1) | (2) | (3) | (4) | (5) | (6) | Local priority | Global priority |
|---|---|---|---|---|---|---|---|---|
| (1) Topology | 1 | 2 | 3 | 2 | 1/2 | 1/3 | 0.153 | 0.033 |
| (2) Modems | 1/2 | 1 | 2 | 2 | 1/2 | 1/3 | 0.114 | 0.025 |
| (3) Node memory | 1/3 | 1/2 | 1 | 1/2 | 1/4 | 1/6 | 0.052 | 0.012 |
| (4) Line speeds | 1/2 | 1/2 | 2 | 1 | 1/3 | 1/4 | 0.080 | 0.017 |
| (5) Type of carrier | 2 | 2 | 4 | 3 | 1 | 1/2 | 0.230 | 0.049 |
| (6) Concentrators | 3 | 3 | 6 | 4 | 2 | 1 | 0.371 | 0.079 |
| $CR.=0.016$ | | | | | | | 0.215 | 1.000 |

Table 8
Systems with respect to 'line speeds'.

| System | (1) | (2) | (3) | Priorities |
|---|---|---|---|---|
| (1) A | 1 | 1/3 | 1 | 0.20 |
| (2) B | 3 | 1 | 3 | 0.60 |
| (3) C | 1 | 1/3 | 1 | 0.20 |
| $C.R. = 0.000$ | | | | 1.00 |

if the priorities of the first level, $p(1)$, are changed to $\hat{p}(1)$, the new global priorities of the $n$th level, $\hat{p}(n)$, are given simply by

$$\hat{p}(n) = W(n,1)\hat{p}(1). \tag{9}$$

This provides a quick sensitivity check which should be carried out in any event. Doing it for this specific example resulted in no change of the preferred system.

## 4. Summary

This paper presents methodological guidelines for selecting a distributed information system for a specified application. In many cases these systems consist of a conglomeration of individual microcomputer system, where each micro- or minicomputer system has its own processing power, software and various types of peripherals. It means that the number of complex system components involved in designing, and in evaluating, distributed systems is even larger than for a single computer system. The intent of this paper is to provide a comprehensive and consistent decision model for evaluating these systems. Experience have shown that the model presented here assists the decision makers in structuring their detailed selection process in a tractable manner and in interacting with both technical and intangible aspects of the problem. Finally, the model's basic structure has been refined to handle the specific needs of various environments regarding the evaluating of other novel information systems.

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