An Analytic Hierarchy Process Approach to Information Systems Development*)

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Abstract

The strategic planning of information systems has been considered a critical issue for management. But there are few tools available for structuring the objectives and scope of the system in the planning stage.

This paper at first gives a brief and tutorial introduction to the Analytic Hierarchy Process(AHP), which is a widely-used decision analysis tool to evaluate multiple alternatives under conflicting objectives. This process constructs a hierarchy to describe the whole problem, decomposes a complex decision problem into subproblems, and makes an overall evalution of alternatives under conflicting objectives.

The author applied the AHP to planning information systems as a way of identifying objectives and areas to be covered by new sysyems. Generally speaking, a hierarchy which describes the development project in a framework of goal, objectives and alternatives is created at the beginning, then refined and evaluated through activities in the planning stage. This process enables management and the development team to communicate with each other better than would occur without the AHP, because they share with each other their understanding of the objectives sought.

Mitchell & Wasil(1989) is one of the earliest applications of the AHP to planning information systems and selecting the application areas from a number of alternatives under multiple criteria. The present author used the AHP in an earlier stage of development and showed a way to clarify the objectives of the development with the AHP. This approach enhances the Critical Success Factor method proposed by Rockart(1979) and Rockart & Crescenzi(1984) by providing a more detailed evaluation of the factors involved.

A case study that used the AHP in planning a system for a company producing and selling non-alcoholic beverages and confectionery in Japan is presented. Further research on how to integrate AHP procedures in the methodology of systems development is presented by a separate paper(Manabe et al., 1991).

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1. New Tools are Needed for Information Systems Planning

Management has begun to feel the need to be involved in the planning and development of information systems. As the strategic use of information systems(IS) has been considered critical for the success of companies, management has to take initiative in starting system development projects.

After reviewing the status quo of information systems planning(ISP), Stegwee & Van Waes(1990) "concluded that ISP has not yet reached maturity (p.19) and other authors wrote that "current methodologies emphasize different stages and only very few seem to touch on the all-important first stage of information systems planning. "(Olle et al., 1989, p.16) This paper discusses the application of the Analytic Hierarchy Process to the planning and development information systems. While most of the traditional methodologies described in textbooks are technical and deal with what is required and how that should be covered by systems, senior management need to consider why they are required. In order for management to be involved in planning information systems, new tools are needed which visualize the fundamental issues associated with business strategies and information systems.

The author used the Analytic Hierarchy Process(AHP) developed by Saaty(Saaty, 1977, 1982; Harker,1989) to plan information systems and has tried to fill the gap between management's needs and technical methodologies. The AHP is a decision-making tool which clarifies the structure of complex problems that select alternatives under conflicting criteria. The process creates a hierarchy to describe the whole problem, evaluates the hierarchy and ranks the alternatives. The AHP has been used in diverse decision-making problems, from private sector to public and international problems(Golden et al., 1989). This process also provide management and IS departments with an effective communication media to discuss the basic issues in developing information systems.

The Critical Success Factor approach(Rockart, 1979; Rockart & Crescenzi, 1984) is useful in planning IS and identifies factors to be considered in planning IS but does not show quantitative priorities among them. The AHP helps management and IS departments establish priorities and determines the factors that should be emphasized in developing information systems. Mitchell & Wasil(1989) is one of the first publications that apply the AHP to IS planning. They selected application areas of the new system under multiple criteria. I have applied the AHP at an earlier stage than they did and covered the activities they did. This paper presents a case-study of how the objectives of a new system were clarified using the AHP and how a system plan was selected from alternatives.

The Analytic Hierarchy Process will be briefly introduced in the next section, the role of the AHP in ISP will be discussed in the following section, and then a case-study of its application is presented in the last section.

2. The Analytic Hierarchy Process

The AHP will be outlined here. Let us consider for example, a business school that wishes to select a computer language or program as the first language to teach to freshmen who have had little or no experience of personal computing.

The first thing for the chairperson of the department to do in making this decision utilizing the AHP is to structure the problem according to the following framework:

goal——criteria——alternatives

and draw a **hierarchy** as shown in Figure 1. The goal is to select a language or program suitable for beginning students. The second level of the hierarchy consists of the criteria for selection:

-Friendly to beginners(denoted as "Friendly" in Figure 1)

-Helpful for understanding data-processing("Data-Prc"),

-Easy to use soon after learning("Usable"), and

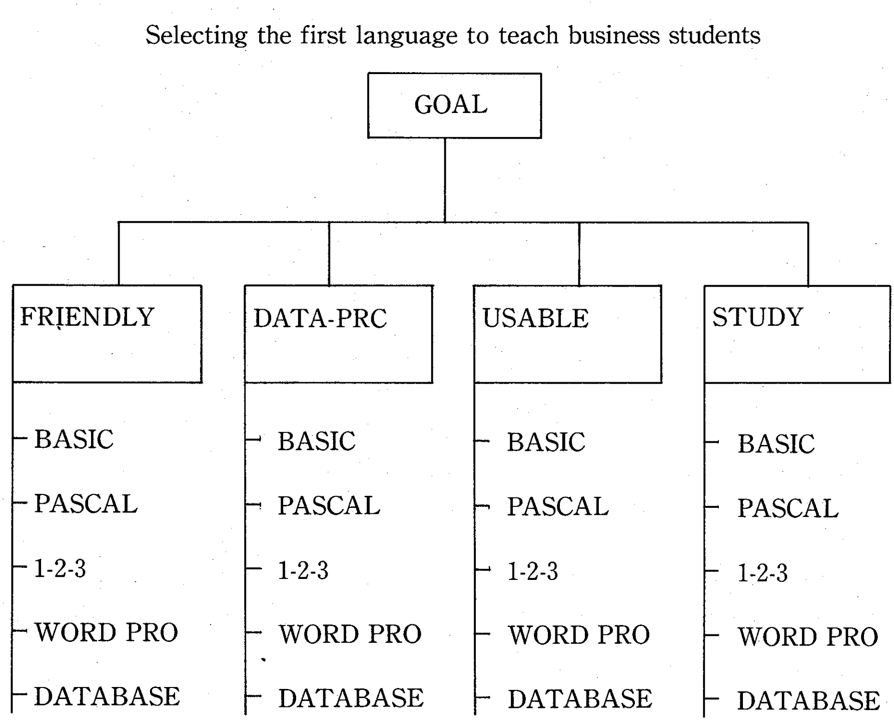
-Useful for further study of computing("Study").

The third level of the hierarchy consists of five alternatives:

-BASIC

-Pascal

Figure 1: Hierarchy Chart for the Example Problem



-Lotus 1-2-3("1-2-3")

-a Word Processing Program("Word Pro"), and

-a Database language such as dBase ("Database").

The hierarchy can be understood as decomposing the problem into four subproblems with a single criterion, in order to consider each subproblem independently. Later we synthesize the results of the four subproblems back into the original problem which gives us the overall weights of the alternatives. The **weights** represent their relative importance under the given criteria.

Suppose we have judged the importance of each criterion relative to the others and obtained numerical weights as follows:

Friendly	Data-Prc	Usable	Study	
0.437	0.326	0.185	0.052	(1)

It requires some technacal assistance to get these weights, which will be described later. Weights are also called **priorities**.

Next, we evaluate the five alternatives with respect to each criterion and obtain the four sets of weights as each column of Table 1 shows. As you see, the sum of the weights for all alternatives on each column is unity.

Table 1: Weights alternatives by criteria

Alternatives	Friendly	Data-Prc	Usable	Study
BASIC	0.054	0.064	0.049	0.117
Pascal	0.061	0.089	0.049	0.463
1-2-3	0.437	0.448	0.432	0.199
Word Pro	0.263	0.227	0.295	0.057
Database	0.184	0.172	0.175	0.165

If you add up the numbers on each row, you will get an overall evaluation for each alternative, subject to the condition that the four criteria are considered to be equally important. But we didn't consider the four criteria to be equally important, as the weights given in (1) show. Then, summing up the numbers on each row of Table 1 weighted by (1) (for example, BASIC is

$$0.054 \times 0.437 + 0.064 \times 0.326 + 0.049 \times 0.185 + 0.117 \times 0.052 = 0.060),$$

we get another overall evaluation of the alternatives with regard to the goal:

BASIC	Pascal	1-2-3	Word Pro	Database	
0.060	0.089	0.427	0.274	0.178	(2)

The overall weights with respect to the goal are called **global weights**(or global priorities) while the weights with respect to the immediate above element are called local weights(or local priorities).

The method of obtaining the weights for items on each level of the hierarchy(as shown by (1) and Table 1) is a matter of deep concern here. It is difficult to compare several items at the same time together to get their relative importance, but easy to compare only two. Saaty(1977) proposed to compare all of the pairs to determine their relative weights. With four items there are($(4\times 3)/2=$)6 pairwise comparisons. Judging which is more important, item i or

Table 2: Scale for Measurement for AHP

If item i is ... then item i	→	Numerical Value(aij)
Equally impotant	→	1
Slightly more impotant	→	3
Strongly more important	→	5
Vely strongly more impotant	→	7
Extremely more important	→	9
Intermediate values	...	2,4,6,8
$a_{ii}=1,\ \ a_{ji}=1/a_{ji}$		

Table 3: Comparison Matrix

	Friendly	Data-Prc	Usable	Study
Friendly	1	2	2	7
Data-Prc	1/2	1	3	5
Usable	1/2	1/3	1	5
Study	1/7	1/5	1/5	1

item j, we give the values shown in Table 2 to a_{ij} and we construct a matrix of relative weight as shown in Table 3. $a_{14}=7$ means that "Friendly" is very strongly more important than "Study." Here we assume $a_{ji}=1/a_{ij}$ and $a_{ii}=1$. We call the matrix of Table 3 the comparison matrix.

Assuming the weights of n elements as $w_1, w_2, ..., w_n$, we consider a_{ij} obtained as an estimate of w_i/w_j. Thus the comparison matrix A may be written as

$$A=\begin{bmatrix} 1 & w_1/w_2 & .....w_1/w_n \\ w_2/w_1 & 1 & .....w_2/w_n \\ & ...... & \\ & ...... & \\ w_n/w_1 & w_n/w_2 & ..... \ 1 \end{bmatrix}$$

If we multiply the vector of weights $\mathbf{w}^T = (w_1, w_2, ..., w_n)$ on the right of A, we get $A\mathbf{w} = n\mathbf{w}$ or $(A - nI)\mathbf{w} = 0$. This means that n is an eigenvalue of A. As A has unit rank and the sum of n eigenvalues is equal to the trace, the sum of the main diagonal elements of matrix A, n is an eigenvalue of A and an only nontrivial solution. We get $\mathbf{w}$ as an eigenvector with respect to the eigenvalue n, then we divide w by their sum to normalize(that is, to make their sum unity).

These calculations are made under the condition that the judgments in pairwise comparisons are consistent, or $a_{ij} = a_{ik} \times a_{kj}$ holds. The degree of inconsistency is evaluated by

$$\text{Inconsistency Ratio} = (\text{Lamda}_{max} - n)/(n-1),$$

where Lamda_{max} is the maximum eigenvalue calculated for A. If the comparisons are consistent, $\text{Lamda}_{max} = n$ and I.R. is equal to zero. It may be tentatively be said that if I.R. is greater than 0.1 then we should review the comparisons. In our example, the I.R.s for every set of pairwise comparisons are below 0.1 and we can consider our judgment practically consistent.

The weight calculations and hierarchy shown in this paper were made using Expert Choice, a software for the AHP. While some academics interpret the above process simply as a way to evaluate multi-attributed items, actually applying the AHP to a number of complicated problems in various areas(Saaty & Vargas, 1982; Golden et al., 1989) gives a new perspective on how to make decisions under complex environments. This aspect of the AHP will be demonstrated using the example in the last section.

3. The AHP in Information Systems Planning

A phased approach or system development life cycle(SDLC) approach has been widely used in developing information systems. SDLC divides the activities of development into several stages; the major stages are analysis, design, development, and implementation. Olle et al. (1989) presents a typical list of stages of system life cycles with two stages added before the analysis stage. The first half of the cycle, up to the stage that builders can start to construct a system, is as follows(Olle et al., p.37):

1.strategic study
2.information systems planning
3.business analysis
4.system design, and
5.construction design.

I agree with their decision to add the first two planning stages to the system life cycle, in order to show senior management the importance of planning in systems development and their involvement in planning. These stages are considered as Information Systems Planning in a broader sense(Lederer & Mendelow, 1986; Stegwee & Van Waes, 1990), and I would like to concentrate here on these stages.

There are various decision problems, large and small, in every stage of a life cycle. In those planning stages, management problems such as why it is required and how it works are major concerns. The answers to these questions identify and establish the objectives and areas to be covered by the system. The conventional tools used and described in systems design textbooks deal mainly with technical or physical decisions such as what factors are required and how they can be realized.

In order to meet this need, the author tried to use the Analytic Hierarchy Process, which assists management to consider general policy in building new systems, enables them to grasp issues more clearly, and involves them in system planning more easily than before. The AHP also provides management and IS departments with a communication tool for discussing the general nature of the system.

In the strategic study discussed above

1. management and the development team should identify what issues in business they want to resolve by building the new system and establish missions or general policy for the system.

For this purpose, or to create scenario of the future, the methodologies presented by Saaty & Kearns(1985) will be useful. The Critical Success Factor(CSF) approach(Rockart, 1979) has been useful to conceptualize issues and identify factors to be considered, but does not explicitly prioritize those factors. Rockart & Crescenzi(1984) wrote that "the transition from a business focus on objectives and CSFs to one on systems definition is not a straightforward, simple process: It is more an art than a science" (pp.108-109). The AHP gives a touch of science to such transitions from CSFs to systems matters by giving more detailed evaluation of factors.

Stage 2, information systems planning, will establish the following:

2. Objectives of the system development project which should be attained in resolving the issues, and

3. Areas to be covered by the system to attain the objectives stated above.

The following example illustrates the use of AHP in this stage.

4. A Case-Study Utilizing the AHP

We applied the AHP in planning the information system for a company which produces and distributes nonalcoholic beverages and confectionery in Japan. The company had some computerized systems which operated independently in each functional department, and was developing a centralized system to integrate the major functions of the corporation.

Figure 2 is a part of the hierarchy which was created at the beginning of the study. The company-wide goal was not clear at this moment and hence is not shown in the chart. This hierarchy emphasizes the functions of each department and appears to be nothing more than the organization chart of the company. We decided that we could not evaluate and resolve inter-departmental issues using this chart, and soon abandoned it.

During a series of discussions several hierarchies were drawn and redrawn, and through these discussions a company-wide business plan was finally identified. The company needed to

Figure 2: A Partial Hierarchy at the Beginning

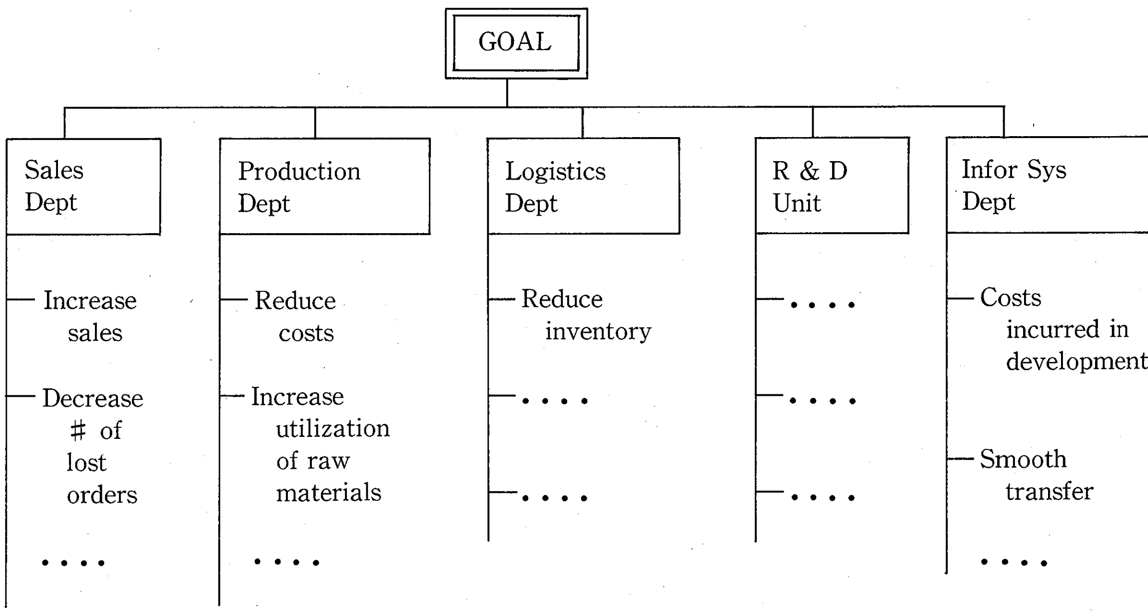


Figure 3: Redefined Hierarchy

Toward Integrated Material Flow From Material through Sales Points

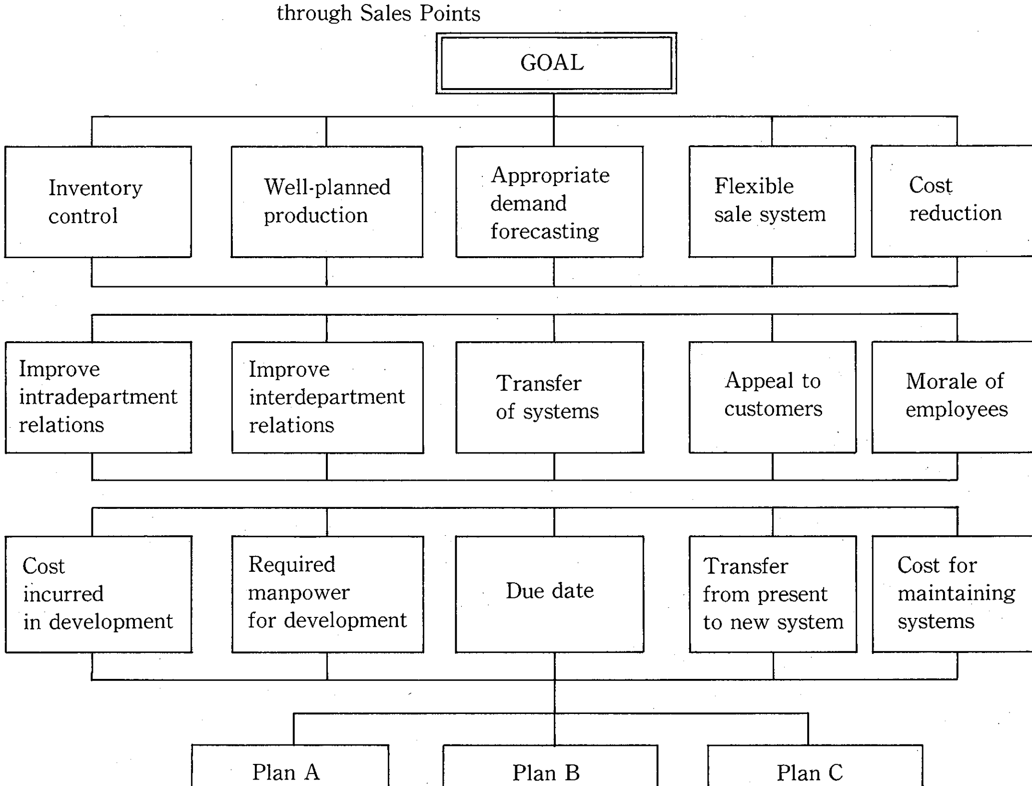
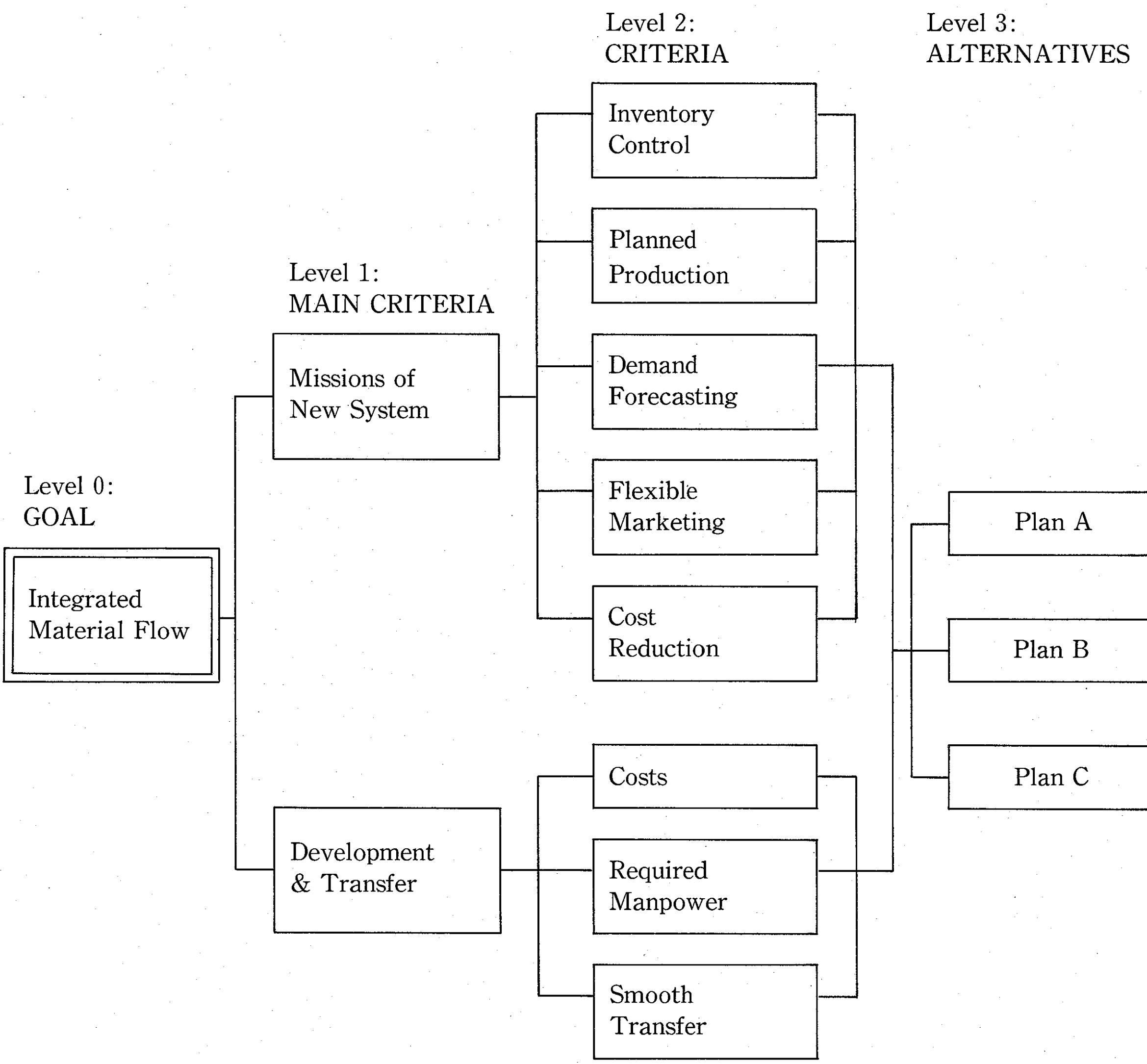


Figure 4: Hierarchy for Information Planning



construct an integrated system which covers information about the flows of raw materials, products in process and inventory at factory stock room, distribution centers, and retail stores. At this stage, the hierarchy shown in Figure 3 was drawn. This chart consists of five levels, and was too complicated for the initial stage of planning.

Next, we distinguished the functions of, or benefits from, the new system from negative factors such as the costs incurred during development, and then made the hierarchy shown in Figure 4. To select those areas to be covered by the new system, in order to attain the above goal satisfying the objectives listed on Levels 1&2, was our problem. The alternatives were as follows:

-Plan A : Covers all the functional areas including production, distribution and sales, and requires large amounts of money, manpower and time.

-Plan B : This was a compromise between Plan A and the limits imposed by its time and cost. The distribution system would not be revised.

-Plan C : This was the most conservative plan which adds only a new inventory system and sub-systems which connect production and distribution functions to the current system. Not many strategic effects were expected until the next development.

The objectives(also called criteria in the AHP framework) for selecting a plan for the new system were grouped under "Missions of New System" and "Development and Transfer". The first five criteria on Level 2 are:

-Inventory Control : Proper inventory control from raw material to inventories at sales points,

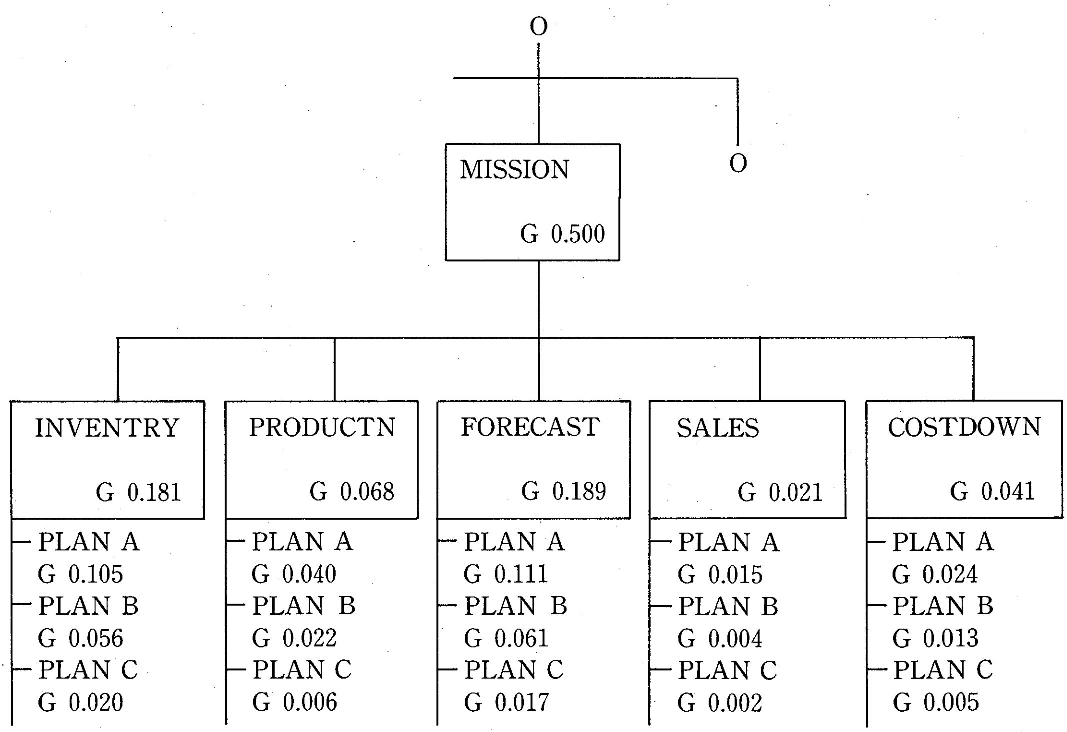
-Planned Production : Well-planned production,

-Demand Forecasting : Appropriate forecasting of demand,

-Flexible Sales : Flexible sales system adaptable to the varying needs of customers, and

-Cost Reduction : Reduction of cost.

Figure 5a: Global Priorities of Objectives



The elements on Level 2 summarized by "Development & Transfer" were associated with development of the new systems and transfer from the current systems to the new:

-Costs : Costs incurred in development and transfer,

-Required Manpower, and

-Smooth Transfer : Smooth transfer from the present system to the new system.

Figure 4 was evaluated next and we got the weights of the criteria and the alternatives. Figures 5a and 5b, hard copies of Expert Choice screens, show the global weights of each

Figure 5b: Global Priorities of Objectives

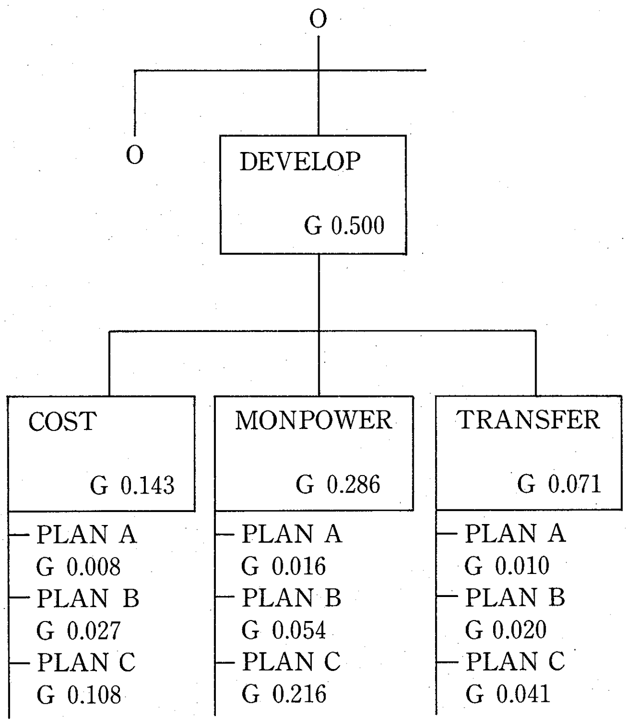


Figure 6: The Overall Weights of Alternatives

Toward integrated material flow production thru sales points

Sorted Synthesis of Leaf Nodes with respect to GOAL

OVERALL INCONSISTENCY INDEX = 0.07

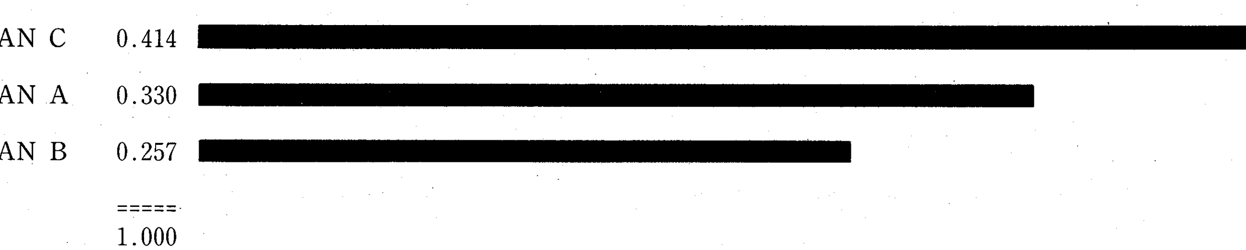
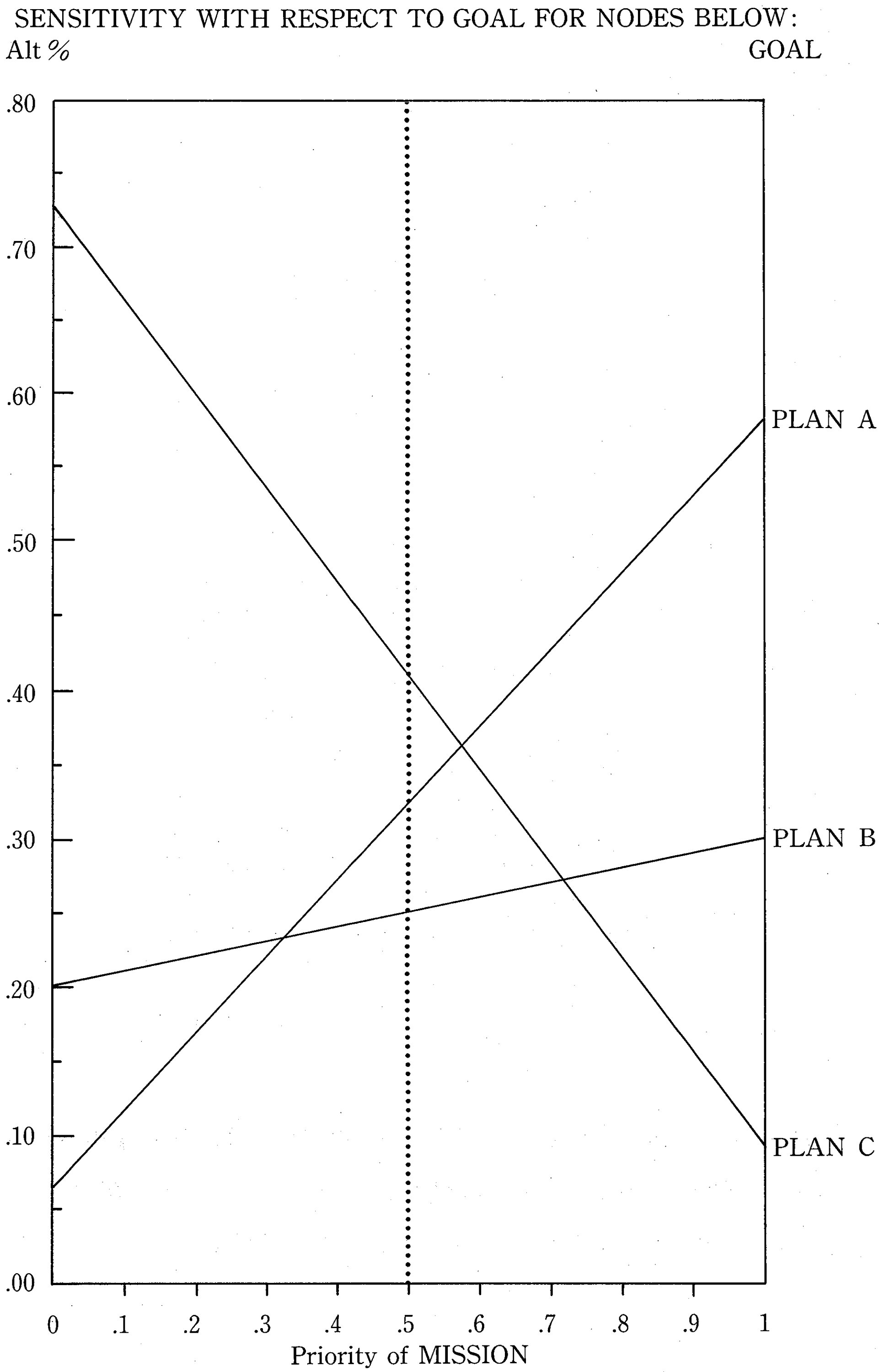


Figure 7: Sensitivity of Criteria to Alternatives



element and Figure 6, the global weights of the three alternatives; this concluded Plan C was preferable. (Expert Choice is a PC software which assists practicing the AHP.) In Figure 4 two criteria on Level 1 were not compared and the two were equally weighted to get the result in Figure 6. If "Mission" had more weight than "Divelopment", Plan A would be preferable to Plan C. If "Development" was judged more important than "Mission", then Plan C would be preferable to Plan A. Figure 7 shows the sensitivity of Level 1 to the global priorities, that is, how the global priorities of the three plans change as the relative weights for two elements on Level 2 change.

Plan A was an ideal model for the company, but management judged the constraints in development and transfer as more problematic and selected Plan C for actual development.

Management and IS staff could understand each other's issues more clearly through hierarchies and evaluations, and communicate more easily than before by using AHP in the planning stage.

I have collaborated with the consultants at PRIDE Japan, Inc. to embed the AHP procedures in PRIDE, a methodology of systems development developed and vended by Milt Bryce & Associates, Inc. (Bryce & Bryce, 1988), especially in its initial study stage. The hierarchies were defined and redefined through activities in the planning stage, and the priorities obtained in the course assist management in making decisions at each activity in each stage. This study was presented in a separate paper(Manabe et al., 1991).

Acknowledgment

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