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Stochastic Expert Choice in Ship Production Project Management

VIIA-1

Ernst G. Frankel, Life Member, Massachusetts Institute of Technology

ABSTRACT

Increasingly rapid and often radical changes in both ship design as well as ship production process technology require more frequent selection from among many alternative technologies and operational strategies under condition of uncertainty. A stochastic time variant hierarchical decision process, or expert choice method, is proposed for use under such conditions. Such an approach is particularly relevant to ship production because here technical decisions usually involve large investments, changes in production or operations and often imply or affect strategic change.

Ship production is complex and capital intensive, as manual production and assembly processes are increasingly automated or replaced by robots. In Japan, for example, more than 10,000 robots were introduced into shipbuilding since 1985 alone. Such radical changes and large scale investments involve complex decisions subject to a multitude of internal and external factors, their associated uncertainties and consequent risk.

Management decisions in ship production often involve several parties, each with its own agenda. Similarly, each will usually attempt to maximize satisfaction with the decision in terms of one or more objectives, which would be affected by the decision.

Achievement of different, often contradicting or conflicting objectives, by different alternative decisions in turn may be influenced by external factors, such as market demand, import prices, labor contracts, government regulations, and environmental constraints. Similarly, endogenous factors such as available credit or existing facilities may affect the contribution of alternatives to the objectives of concern.

Shipbuilders have traditionally delayed major change decisions until the last moment and often until it was too late to solve a problem. The reason was largely risk aversiveness of shipyard management, an unfortunate attitude in an industry subject to large uncertainties and risks.

Expert choice, or the analytic hierarchical process (AHP), offers an approach which allows consideration of all the factors, as well as the risk attitudes of the decision makers and others involved. The basic AHP method was modified to permit consideration of the probabilities associated with hierarchical relationships of factors and decision makers. AHP is further suggested to include the effect of time on the determination of the risk, and time dependence of the outcome of alternative decisions. Thereby AHP permits determination of not only the most effective choices, but also timing of complex decisions met so frequently in ship production project management.

INTRODUCTION

Most decisions, particularly management decisions in ship production, involve multiple objectives and various alternatives. The performance of alternative decisions in terms of their contribution to the objectives often requires consideration of several levels of factors.

Considering a decision for a new welding process, for example, the first level of choices may be among fully automated, semi-automated, or manual and a number of brand or models in each category. Objectives may include welding costs, weld quality, labor skill, work environment and pollution, capacity, expandability, and more.

The next level, welding costs, may have to be divided into capital and operating or fixed. variable, average, and marginal costs. To relate the performance of decision alternatives to such objectives, intermediate factors such as power and material consumption, rate of production, and more must be introduced.

Similarly, they may find that for a particular choice, output or production rate may affect quality and therefore performance relating to one objective measure, say quality, may well be affected by performance relating to another objective, such as operating costs. This type of decision problem is most effectively represented as a hierarchy shown in Figure 1, where each alternative contributes in some way to factors which in turn impact on performance measures which establish the value of the various objectives.

The different objectives in such a multi-objective decision problem usually have a relative importance or comparative weight for the decision makers. In this paper, the analytic hierarchy process, first suggested by Saaty (l), is applied to ship production project decision problems, and expanded to handle consideration of uncertainty and risk.

ANALYTIC HIERARCHICAL DECISION MODELS

Ship production project management involves, among others, decisions such as choice of production and assembly processes to be used, and of equipment or material to be procured for a particular ship production project.

Such decision processes usually involve one or more decision makers, several often conflicting or even contradictory objectives, multiple performance measures, and various choices. Choices may be unique and independent of timely time variant in terms of their availability, performance, or cost. Similarly, certain risks may be associated with each choice and the weight decision makers place on different objectives may also be uncertain within defined limits.

Assuming a decision hierarchy, as defined in Figure 2, consisting of 4 levels with a single decision maker, the shipyards project manager, who has to choose from among several different pumps for a ship under contract.

Objectives can be ship cost, operating efficiency, etc. while performance measures can be pump cost, installation manhours, and Pump performance. Each factor at one level is related to each of the factors at the next higher level in turn, using the comparative weight or contribution it makes to the factor at the next higher level. For example, if pumps 1, 2, and 3 are expected to have relative costs of 1, 1.5, and 2 compared to Pump 1, respectively, and pump 3 is expected to twice as expensive as pump 2, then information is related by a comparative weight (relative cost) matrix of PumP alternatives with respect to procurement costs shown in Figure 3.

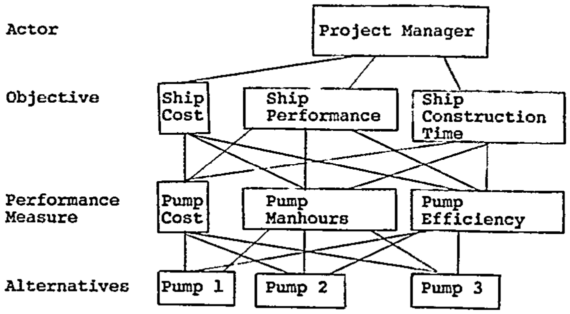

FIGURE 2 - Pump Selection Problem

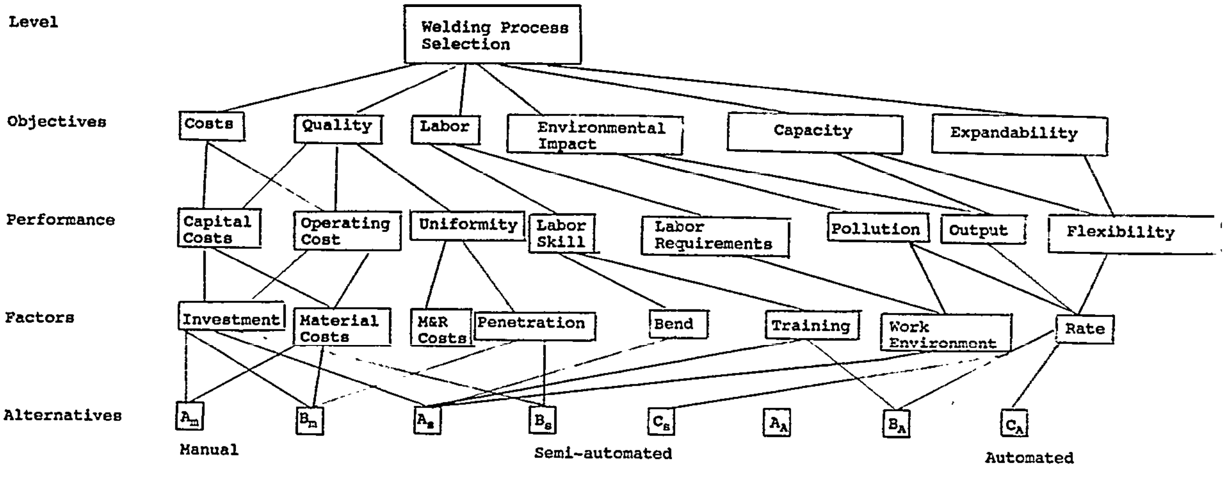

FIGURE 1 - Simple Hierarchical Decision Problem in Shipbuilding

		Pump		
		1	2	3
	1	1	3/2	2
Pump	2	2/3	1	2
	3	1/2	1/2	1

Fig. 3 Pump Procurement Cost Comparison Matrix

There may be some inconsistency in such comparative weighting. This though is easily determined by consistency analysis as shown later in this article. Similar comparison matrices can be drawn up for the pumps with respect to the other factors at the next level (performance measure) as follows.

		Pump		
		1	2	3
	1	1	1/2	1/2
Pump	2	2	1	1
	3	2	1	1

Fig. 4 Comparative Weights with Respect to Installation Manhours

		Pump		
		1	2	3
	1	1	3	2
Pump	2	1/3	1	1/2
	3	1/2	2	1

Fig. 5 Comparative Weights with Respect to Pump Efficiency

Next, each of the performance measures relates to each of the objectives in turn, and finally assumes the relative weight or importance the shipyard decision maker plans on these objectives (ship cost, ship performance, and construction time). As a result, we obtain 3 (3x3) comparative weighting matrices between each of the three lower levels and one (3x3) matrix relating the second (objective) level of the matrix to the shipyard decision maker. The purpose of this analysis is to determine the optimum choice of the shipyard decision maker considering all the comparative weights or rankings.

To obtain the weights of each alternative with respect to a performance measure, a logarithmic least square or eigenvector method is used. The latter computes the principal right eigenvector of each matrix which can be shown to represent the weight of each alternative with respect to the performance measure considered, and is usually preferred.

The weights are usually obtained as pairwise comparative weights by judgement or from actual data. For example, if fuel consumption and reliability are two factors against which two machines, A and B, are to be weighted, and A consumes on average 50% more fuel than B, then the comparative weighting matrix is shown in Figure 6.

	A	B
A	1	3/2
B	2/3	1

Fig. 6 Comparative Weights of Machines A and B Against Fuel Consumption

Comparative reliability may be estimated from interviews, or from Delphi type experiments which may give results that are not fully consistent such as (Figure 7)

	A	B
A	1	5/2
B	2	1

Fig. 7 Comparative Weights of Machines A and B Against Reliability

DETERMINISTIC ANALYTIC MODEL SOLUTION METHODS

If A is a matrix of the form

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} \\ 1/a_{12} & 1 & a_{23} \\ 1/a_{13} & 1/a_{23} & 1 \end{bmatrix} \qquad (1)$$

where a,, is the comparative weight of i compared to j with respect to the factor against which their performance is measured, and w_1 and w_j are the priority weights of i and j, then $w_i/w_j = a_{ij}$ for all pairs i, j.

In the ideal case with complete consistency, all a,, = $w_I/w_j = a_{ir}a_{rj} = w_iw_r = w_iw_r/w_rw_j$ and $a_{j1,} = 1/a_{ij} = w_j/w_1$ and $w_1 = a_{ij}w_j$ (i,j=1,2,.. ....n) as well as
The purpose is to obtain an unbiased vector of the weights of the alternatives

$$w_1 = \frac{1}{n}\sum_{j=1}^{n} a_{ij}w_j(i,j=1,2....n) \qquad (2)$$

i=1 . . ..n with respect to each of the factors at the next higher Usually a_{ij} - $w_{j\backslash i}/w_j$ but perturbations of this rate will usually occur. If λ_{max} = maximum eigenvalue of the matrix A, then

$$\lambda_{max} = (\sum_{j=1}^{n} a_{ij}w_j)/w_i \; (all\ i) \qquad (3)$$

The eigenvector of A can be obtained in different ways, to determine the weights of the ith with respect to the factor at the next level. An approximate, yet simple, way is to sum the entries a_{ij} in each row and divide by the sum of the *rows,* or for

$$A = \begin{bmatrix} 1 & a_{12} \\ a_{21} & 1 \end{bmatrix} = \begin{bmatrix} (1+a_{12}/S \\ (1+a_{21}/S \end{bmatrix} \qquad (4)$$

where $S = (2 + a_{12} + a_{21})$

As the a, - l/a it is necessary to measure if the values a_{ij} and a_{jj} (all i) are consistent. This can be performed by using the eigenvector (or the maximum eigenvalue λ_{max}) to measure consistency of ~~the~~ matrix A. $(\lambda_{max} - n)$ / (n-l) = "consistency index" is a useful measure of consistency. Using a Random Inconsistency Index (R.I.I.) developed by Saaty [l] computed by random tests where R-I. is found to be

n	R I
	0
2	0
	0.58
2	0.90
5	1.12
6	1.24
7	1.32
8	1.41

We can now determine the consistency ratio C.R. = C.I./R.I. which should have a value of C.R. ≤ 0.1 for acceptable consistency. The C.R. > 0.1 judgements on comparative weights may have to be revised.

A more accurate way to compute the priority or eigenvector $[w_i]$ is to raise A to increasing powers of K and then normalizing the result:

$$P^K = \lim_{K \to \infty} A^k e/e^T A^K e$$

where e = (l,...l) and for K = 1

$$P^1 = Ae/e^T Ae$$

and second estimate

$$P^2 = A^2 e/e^T A^2 e$$

This is continued until iteration K when the process converges and the normalized weights of w_i remain constant from iteration to iteration.

DETERMINISTIC DECISION EXAMPLE IN SHIP PRODUCTION

Assume a very simple three stage problem, as shown in Figure 8, where the production manager and controller are assumed to have relative weights of 1/3 to 2/3 respectively, the pairwise comparative weights of A and B, use of building ways and built-in dock, with respect to C, D, and E and their priority vectors are,

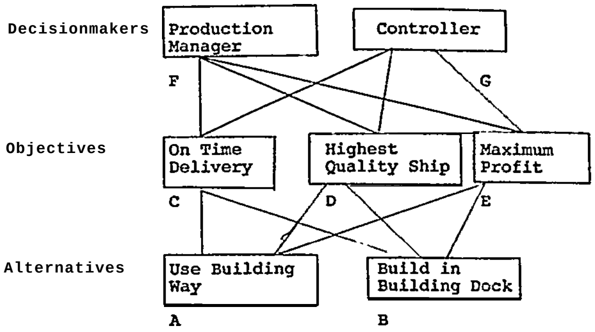

FIGURE 8

A and B with respect to C - On-time delivery

	A	B	Priority Vector
A	1	1/2	1/3
B	2	1	2/3

A and B with respect to D - Highest Quality Ship

	A	B	Priority Vector
A	1	3/2	25/39
B	2/5	1	14/39

A and B with respect to E - Maximum Profit

	A	B	Priority Vector
A	1	4/3	14/25
B	1/2	1	9/25

Next we obtain the priority vectors of C, D, and E with respect to F, the production manager, and with respect to E, the controller, as follows.

With respect to F

	C	D	E	Priority Vector
c	1	5/4	1/2	33/133
D	2/3	1	2/3	28/133
E	2	3	1	72/133

And with respect to G

	C	D	E	Priority Vector
c	1	1	2	240/574
D	1	1	3/2	210/574
E	2/5	2/3	1	124/574

The priority vectors for F or G are obtained by multiplying the matrix of priority vectors of A and B with respect to C, D, and E by the priority vectors of C, D, E with respect to F and G respectively viz:

<u>Priority Vector with respect to production manager:</u>

$$\begin{array}{cc} & \begin{array}{ccc} C & D & E \end{array} \\ \begin{array}{c} A \\ B \end{array} & \begin{bmatrix} 1/3 & 25/39 & 14/25 \\ 2/3 & 14/39 & 9/25 \end{bmatrix} \end{array} \begin{bmatrix} 33/133 \\ 28/133 \\ 72/133 \end{bmatrix} = \begin{bmatrix} 0.52 \\ \\ 0.48 \end{bmatrix} .$$

and Priority Vector with respect to controller

$$\begin{array}{cc} & \begin{array}{ccc} C & D & E \end{array} \\ \begin{array}{c} A \\ B \end{array} & \begin{bmatrix} 1/3 & 25/39 & 14/25 \\ 2/3 & 14/39 & 9/25 \end{bmatrix} \end{array} \begin{bmatrix} 240/574 \\ 210.574 \\ 124/574 \end{bmatrix} = \begin{bmatrix} 0.495 \\ \\ 0.505 \end{bmatrix}$$

With the relative weight (or importance) of the two decision makers of 1/3 and 2/3 respectively, the final priority weights of decision alternatives A and B are therefore

$1/3 \times 0.520 + 2/3 \times 0.480 \quad 0.493$

$1/3 \times 0.495 + 2/3 \times 0.505 \quad 0.507$

In other words, alternative B has a slightly higher weight.

STOCHASTIC EXPERT CHOICE DECISION MAKING

In ship production, the pairwise comparative weights are often quite uncertain and, instead of unique pairwise comparative weights, one can often obtain only probabilistic or conditional probabilistic pairwise weight comparisons. In the simplest case a range of pairwise comparison weights are given, a_{ijmax} *and* must then obtain the consistent range of a_{ijmax} *and* a_{ijmin}

Conversely, the a_{ij} may be conditioned on some weight a_{ke}. If a range (is given, it is usually possible to determine the consistent range of a_{ij} max - a_{ij} min) or vice versa. Using the resulting extreme consistent values, the range of values of the priority weights $w_{imax} - w_{imin}$ (i=l....n) for all the matrices in the hierarchy can be determined, and ultimately the range of the priority weights of the alternatives is a function of the characteristics of the hierarchy.

In a simple trivial example, it may be assumed that the comparative weight of the production manager is at least one quarter, but no more than 2/5 ths in relation to the controller and that the controller's weight is at least one half but no more than 3/4 ths in relation to the production manager.

After checking for consistency, one could now determine the range of comparative weights of the two decision alternatives between the extreme values obtained. Using standard statistical techniques, one could also determine the expected comparative weight.

The same method can be used when there are ranges in comparative weights at more than one level in the hierarchy.

CONCLUSION

Expert choice hierarchical decision models are useful tools for the solution of complex multi-criteria, multi-level decision problems which abound in ship production. The simple examples presented may seem trivial but the method proves to be quite powerful in the solution of large, full-scale real world problems.

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