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EVALUATING TANGIBLES AND INTANGIBLES OF CAPITAL INVESTMENT

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ABSTRACT

Capital budgeting techniques, such as discounted cash flow analysis, are used extensively in the evaluation of capital investment projects in business. The techniques, however, are not employed without flaws, among which are the overreliance on quantitative analysis while ignoring other intangibles and qualitative factors. The objective of this paper is to propose an adjunct methodology - the Analytic Hierarchy Process - for making capital investment decisions. The methodology is superior to other techniques alone because (1) it incorporates both tangibles and intangibles, quantitative and qualitative factors in the analysis; (2) it improves the consistency in judgment as compared to one multiple-attribute decision model; and (3) it is flexible as the hierarchical structure can be modified easily without substantial disruption in its performance.

EVALUATING TANGIBLES AND INTANGIBLES OF CAPITAL INVESTMENTS

Introduction

Despite the fact that substantial efforts have been made towards refining existing capital budgeting techniques (see for example, Woods and Randall, 1989; Meyer, Besley and Longstreet, 1988; Prakash, Dandapani and Karels, 1988; Coulthurst, 1986a; 1986b) and towards developing new ones (see for example, Kwan and Yuan, 1988; Miltenburg and Krinsky, 1987), practitioners are still concerned about the problem of the "correct way" to make capital investment decisions (Weaver, Peters, Cason, and Daleiden, 1989; Weaver, Clemmens, Gunn and Dannenburg, 1989). This is because many of the refinements and new models developed continue to ignore the multitude of intangible parameters that are crucial to making the "correct" investment decisions. For instance, many of the intangible benefits of advanced manufacturing technology, such as flexibility, improved quality, delivery, throughput, etc., are difficult to measure and hence, are often disregarded or relegated to the list of imponderables when applying capital budgeting techniques. If a company consistently rejects investment proposals which ignore intangible benefits, its long-term viability may be at risk. Thus, capital budgeting decision models need to be improved to incorporate such intangible benefits in the analysis (Polakoff, 1990) and different criteria need to be used as the nature of the investment projects becomes more complex (Howell and Soucy, 1987).

This paper proposes a way of coping with intangibles and qualitative factors in capital investment analysis, using the Analytic Hierarchy Process. The analytic hierarchy process provides a method of including tangibles and intangibles, quantitative and qualitative items for decision making. By allowing all relevant factors to be evaluated objectively, the analytic

hierarchy process can improve on current capital budgeting techniques which tend to be entrenched in the quantitative aspects of the decision.

The paper first describes the analytic hierarchy process. An application of the method to capital investment analysis is next made by means of a case example. Finally, the paper discusses various approaches to solving the case, i.e., traditional capital budgeting techniques (discounted cash flow models), the multiple-attribute decision model,[1] and the analytic hierarchy process. As the case analysis shows, the use of the analytic hierarchy process contributes richness and regularity to capital investment analysis which goes beyond the myopic quantitative fixation so common in such analysis. By incorporating more than just the quantitative data, the analytic hierarchy process may also aid in meshing investment decisions with overall corporate strategy, not just the financial goals.

The Analytic Hierarchy Process

The Analytic Hierarchy Process was developed by Saaty in the 1970's as a decision aid to help solve unstructured problems in economic, social and management sciences. The analytic hierarchy process has been applied in a variety of contexts: from the simple everyday problem of selecting a school (Saaty, 1980, pp. 25-28) to the complex problems of designing alternative future outcomes of a developing country (Saaty, 1977), evaluating political candidacy (Saaty and Bennett, 1977), allocating energy resources (Saaty and Mariano, 1979), and so on. It has also been applied to business problems such as selecting portfolio investments (Saaty, Rogers and Pell, 1980), assessing the impact of assumptions on business forecasts (Jensen, 1983a), establishing relative priorities of analytical review procedures (Arrington, Hillison and Jensen, 1984), evaluating the pros and cons of various cost-volume-profit models (Driscoll, Lin and Watkins, 1984), incorporating stochastic inflation rates and risk premiums in capital budgeting (Jensen, 1987) and evaluating the

costs and benefits of internal control measures (Bagranoff, 1989). By and large, existing evidence indicates that the analytic hierarchy process is a useful methodology for solving socio-economic problems where qualitative factors have significant impact on the decision.

In general, the analytic hierarchy process can be summarized in terms of its three prinicipal component processes. First, the decision problem is structured into a hierarchy where each level consists of a set of elements. The top level usually consists of the goal of the decision problem; lower levels are made up of criteria, subcriteria and alternatives, depending on the problem at hand. The use of hierarchies in structuring a complex problem is appealing because the interrelationship among the decision variables can be identified, making the analysis simpler and more manageable. Exhibit 1 gives an example of a hierarchy where investment opportunities for a multinational in three countries are evaluated against five major criteria such that the firm's shareholder wealth is maximized.

Insert Exhibit 1 here

Once the hierarchy is described, the elements of each level are evaluated by using pairwise comparison and considering their relationship to a particular element above, such that local priorities of the elements in question can be established. For instance, regarding the five criteria used in evaluating foreign investment opportunities, as given in Exhibit 1, a total of ten pairwise comparisons have to be performed by the decision maker. He would have to determine "how much more (less) important one criterion (e.g., levels of economic development) is over another (e.g., geographic location/infrastructure) in maximizing shareholder wealth?". A nine-point scale[2] is used to record these pairwise comparisons, as recommmended by Saaty

(1980), and these results are then used as inputs to determine the local priorities of the elements as perceived by the decision maker.

The third and final process of the methodology is to establish local as well as global priorities of the elements in the hierarchy. To illustrate this procedure, let us assume that the objective is to establish the relative weights of n criteria. If we denote their weights by w_1, w_2, w_3, ... and w_n, the pairwise comparison matrix **C** may be expressed as the following reciprocal matrix:[3]

$$\begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ \cdot \\ \cdot \\ \cdot \\ C_n \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots & C_n \end{array} \\ \begin{bmatrix} 1 & w_1/w_2 & w_1/w_3 & \cdots & w_1/w_n \\ w_2/w_1 & 1 & w_2/w_3 & \cdots & w_2/w_n \\ w_3/w_1 & w_3/w_2 & 1 & \cdots & w_3/w_n \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ w_n/w_1 & w_n/w_2 & w_n/w_3 & \cdots & 1 \end{bmatrix} \end{array}$$

Using **w** as the vector of weights, we postmultiply the matrix **C** by the column vector **w** and obtain the vector n**w**:

$$\mathbf{Cw} = n\mathbf{w}$$

$$\mathbf{Cw} - n\mathbf{w} = \mathbf{0}$$

$$(\mathbf{C} - n\mathbf{I})\mathbf{w} = \mathbf{0}$$

$$\mathbf{w} = (\mathbf{C} - n\mathbf{I})^{-1}\mathbf{0} = \mathbf{0}$$

Therefore, for **w** to possess a nontrivial solution, the value of n must be such that **C** - n**I** becomes a singular matrix. This is a familiar eigenvalue problem, and the eigenvector approach[4] is, therefore, recommended as the methodology for deriving local priorities (Saaty, 1980, pp. 49-53).

The local priorities of elements at each level are then weighted by the priority of the element in the higher level with respect to which the evaluation is being made. By continuing this process of eigenvector extraction and prioritization by weighting, a global priority vector for the decision problem is derived. For instance, the global priority vector for the hierarchy given in Exhibit 1 will be a relative ranking of the investment opportunities in the three countries. Since elements of the global priority sum to one, it not only aids the multinational in determining where to invest but also suggests the proportion of resources to be allocated to each country, given that they all are sound economic investments.

Despite the fact that analytic hierarchy process appears to be superior to other ad hoc weighting schemes for multiple-criteria decision-making because it insures consistency and transitivity of responses through the use of pairwise comparisons, it does have its critics. The model has been criticized because of the potential ambiguities of the questions used in the pairwise comparisons, the supposedly non-rational basis of the nine-point scale, and the potential for rank reversal which may occur when an "identical" alternative is added to the problem (Dyer, 1990). All of these criticisms have been answered at length by Saaty (1986, 1987, 1990), by Saaty and Vargas (1984a, 1984b) and by Harker and Vargas (1987, 1990). In sum, the analytic hierarchy process provides a more comprehensive and consistent means to simultaneously weigh multi-attribute alternatives than other available decision tools. Its application in multiple-criteria decision-making will be illustrated in the next section with a capital investment case.

Capital Investment Case

Exhibit 1 shows the way in which the analytic hierarchy process can be used to evaluate the capital investment opportunities of a multinational, given its goal of shareholder wealth maximization.[5] All five criteria in

Exhibit 1 are qualitative in nature, and a major contribution of the methodology is that it incorporates qualitative criteria systematically into the decision-making process, a procedure which has been largely ignored in many capital investment decisions. The Standard Industrial Tools case to which we now turn provides a richer example of the way in which both tangible and intangible, quantitative and qualitative factors can be analyzed within the framework of the analytic hierarchy process as compared to other capital budgeting techniques.

Standard Industrial Tools Inc. (SIT) is a recognized leader in the design and manufacture of precision machine tools used in the U.S. market. Since the market for machine tools is both intermediate and industrial, the company has been less concerned with price competition than with prompt delivery and consistent quality of the product.

Mr. Stanford, the founder and President of SIT, wants to ascertain the company's record of profitability and to ward off any potential threat of international competition. He believes that the only way to develop a sustainable long-term competitive advantage over his existing and potential competition is to take a quantum leap in both new technology and cost leadership. For the past three months, the board of directors has been debating the acquisition of an automated flexible manufacturing system (AFMS), as recommended in the capital expenditure proposal prepared by Mr. Stanford and his vice-presidents. Included in the proposal are three alternatives: AFMS-X, AFMS-Y and AFMS-Z; the relevant data on the three systems are summarized in Exhibit 2.

Insert Exhibit 2 here

Among the data presented are the net present value (NPV), internal rate of return (IRR) and payback period for the three alternative automation

systems. In computing these numbers, Mr. Stanford and his vice-presidents have been very cautious in forecasting the future cash flows and believe that they have applied the discounting techniques correctly. In addition to these financial measures, other measures such as the annual operating margin, the levels of investments and savings are included. Since delivery time and consistency of quality are keys to SIT's past success, data regarding the attainment of schedule, process yield, throughput time and lead time are included. Finally, as technology and cost leadership are vital to SIT's future success, the proposal also includes an analysis of the alternative system's impact on the company's production process, research and development, technology and product obsolescence.

The board of directors has been debating this proposal for some time and has not yet reached a conclusion. The reason for such prolonged debate is that even though Mr. Stanford has recommended the purchase of AFMS-Z because of its high NPV, high IRR and short payback period, its performance in terms of schedule attainment, process yield and throughput time is the worst among the three alternatives. In addition, AFMS-Y seems to be the preferred alternative, as compared to the other two, if technological innovation is considered to be crucial to SIT's success in the future. Because the board of directors recognizes that there are many factors affecting the decision, they fear that some may have been overlooked in the recommendation. Accordingly, the board is seeking advice about the selection of the "best" automated flexible manufacturing system for the company.

In the following section, three approaches to solving SIT's problem are presented. They are the commonly used discounting techniques, the multiple-attribute decision model proposed by the Computer Aided Manufacturing International and the analytic hierarchy process presented in this paper.

Approaches to Capital Investment Decisions

(A) Capital Budgeting Techniques - Discounted Cash Flow Analysis

Discounted cash flow analysis is widely used in practice and detailed instructions on its application is readily available.[6] Using discounted cash flow analysis, it is obvious that AFMS-Z should be chosen since it has the highest NPV and IRR of the three alternatives. On this basis, Mr. Stanford's recommendation of AFMS-Z is legitimate, given the decision rule implicit in the technique. The technique is deficient, however, in that it relies solely on quantitative analysis and it ignores other indirect cost savings and intangible benefits, which in this case are such factors as throughput time, process yield, schedule attainment, basic research and development, and product and technology obsolescence. Therefore, because it does not take all these factors into account, and it concentrates only on data measurable in financial terms, the discounted cash flow analysis may produce a suboptimal recommendation by suppressing or ignoring significant information.

(B) Multiple-Attribute Decision Model

The multiple-attribute decision model (MADM) is basically a management tool for project selection that allows the decision maker to set priorities for projects and rank them while considering the critical factors for a project's success, factors which go beyond purely financial measures. Like the analytic hierarchy process and discounting techniques, the crucial aspect of the MADM is to define the problem clearly. Once the problem is stated, the MADM follows a rather straightforward procedure which begins by identifying the critical factors and then classifying them into three groups: quantitative-financial, quantitative-nonfinancial and qualitative factors. The decision maker then assigns a weight to the critical factors, out of a total of 100 - a larger weight denotes a greater importance of one factor over

another. As well, for each critical factor, a scale of 0 to 5 is created,[7] the nature of which relates to the factor involved.

Using these scales, each of which is uniquely related to its respective critical factor, scalar values are assigned to the project alternatives for each of the critical factors. MADM also incorporates a risk adjustment by assigning a confidence level (confidence level of zero implies maximum risk; confidence level of one means no risk) per factor for each of the alternative projects. The priority scores for the alternative projects are then computed by summing the products of the weight, scalar value and confidence level over all critical factors. The decision maker has only to select the project which has the highest priority score, since this is the alternative which presumably maximizes the values of the critical factors while minimizing the risk.

When we apply the MADM to the SIT capital investment case, the priority scores of AFMS-X, AFMS-Y and AFMS-Z are 296.3, 294.2 and 292.6 respectively.[8] That is, MADM priorities suggest that AFMS-X should be chosen because its score is the highest of the three automation projects. As can be seen, the signal given by the MADM (AFMS-X) is different from that given by the discounting techniques (AFMS-Z). This difference arises from two sources inherent in MADM that represent improvements over discounting techniques: (1) the MADM considers all the critical factors of the investment decision, not just NPV and IRR as discounting techniques do; (2) the relative riskiness of the projects are explicitly assessed through the confidence levels whereas risk-adjusted discount rate and probability theory are the tools used in discounting techniques for handling risk.

Although the MADM does improve on simple discounting techniques, there are still some structural weaknesses in the model. For example, it is difficult to assign weights to a large number of critical factors while preserving consistency and transitivity of judgments. Problems can also arise

with the MADM if the priority scores calculated for the alternatives are not significantly different. Although a priority score may be the highest among the group of alternatives, the project may not be the best alternative because of small deviations among the scores which cannot be tested for significance. For example, the difference between the best and worst priority scores for the projects considered in the SIT case is 3.7. This 3.7 represents only about 1% of the best score which implies that anyone of the three automation projects may be equally acceptable. Thus, although the MADM improves on the simple discounting techniques, it does itself have problems with subjective weighting and clearly signalling an optimal decision.

(C) Analytic Hierarchy Process

The analytic hierarchy process may provide a way of correcting the flaws inherent in the MADM and in simple discounting techniques, since the weighting procedure used provides a logically consistent set of weights which insure transitivity relationships among the critical factors. As well, the analytic hierarchy process considers all relevant information. Applying the analytic hierarchy process to the SIT investment case, one must first describe the hierarchy implied by the case and then undertake the required pairwise comparisons, eigenvector computations and prioritization by weighting.

As illustrated in Exhibit 3, the analytic hierarchy process includes a total of 17 critical factors in the analysis, comprising two levels of criteria and subcriteria in the hierarchy. In this case, the critical factors are classified into four major groups: quantitative-financial, quantitative-nonfinancial, qualitative-nonrisk-related and qualitative-risk-related. The first three groups of factors corresponds to those analyzed within the MADM framework and the fourth represents an analogue to the confidence level analysis of risk included by the MADM. Thus, the hierarchy of the critical

factors constructed for the analytic hierarchy process tries to incorporate all of the information used in the MADM.

Insert Exhibit 3 here

Exhibit 4 contains the local priority vectors derived from each stage of pairwise comparison as well as the global priority vector as determined from the weighting process.[9] The results indicate that the three alternatives rank in the order of AFMS-Y, AFMS-Z and AFMS-X. Accordingly, AFMS-Y is the preferred automation project using the analytic hierarchy process.

Insert Exhibit 4 here

It is not surprising to find that the project selected on the basis of the analytic hierarchy process is different from that signalled by the MADM. The difference in results arises from the variance of the methods which the two techniques used in setting priorities for the criteria, i.e., the pairwise comparisons of the criteria and eigenvector computations used in the analytic hierarchy process versus the **ad hoc** assignment of weights used by the MADM. Although pairwise comparison of the criteria involves more time and effort on the part of the decision maker than does the ad hoc assignment of weights to the criteria, it nevertheless improves the consistency of responses involved in the process. For example, if criterion A is weakly more important than B (score of 3) and B is as equally important as C (score of 1), then A must also be weakly more important than C (score of 3). Thus by using the pairwise comparisons, the analytic hierarchy process helps to improve the consistency of judgment by enforcing compliance with the rules of logical transitivity, while maintaining an accurate intensity of preference of one criterion (or alternative in relation to the criterion) over another.

There are other advantages offered by the analytic hierarchy process over the MADM. For instance, by classifying the 17 critical factors into four major groups, the decision maker only has to handle a maximum of six factors (quantitative-financial) at a time. Obviously, it is simpler to compare six factors on a pairwise basis than to assign weights to a total of 17 factors as in the case of the MADM. Also, the overall rankings of the alternatives, as given in the final vector [0.2702, 0.4095, 0.3203] (Exhibit 4), can be used as a basis for resource allocation. If, for example, the alternatives are independent investment projects, then the total funds can be allocated to the projects AFMS-X, AFMS-Y and AFMS-Z in the ratio of 0.2702:0.4095:0.3203[10] respectively. One of the major strengths of the hierarchy employed in the process is its flexibility:[11] additions (or deletions) to a well-structured hierarchy will not disrupt its performance. For instance, another level (e.g., three possible states of the world - pessimistic, status quo and optimistic) can be added to the hierarchy in Exhibit 3, without causing any major impact on the analysis. Thus with this flexibility of a hierarchy, the decision problem formulated with the analytic hierarchy process can be adjusted quickly to changes in the company's operating environment.

Concluding Remarks

Making sound investment decisions concerns financial practitioners and theoreticians alike. Most agree that more than simple quantitative analysis is required to make investment decisions which comply with the strategic goals of the company to ensure long-term profitability. This paper has proposed a different methodology from the common variations on discounted cash flow technique - the Analytic Hierarchy Process - for assessing capital investment projects. The analytic hierarchy process does require substantial setup time and a concerted effort to implement. While this is a cost or drawback of the methodology, the improvement to the quality of the investment decision

provides a countervailing benefit. Decision quality is improved because both quantitative and qualitative criteria are evaluated in the analytic hierarchy process. This provides a richer information set supporting the investment decision than the discounting techniques. The analytic hierarchy process reduces the number of criteria to be analyzed at one time by aggregating similar criteria into groups, thus making the evaluation process simpler than the MADM. As well, the use of the pairwise comparison process to set priorities for criteria improves consistency over other ad hoc weighting schemes. The output of the process, the global priority vector, does more than simply providing an overall ranking of the alternatives. Since this resultant vector represents the product of preference ratings over criteria and projects, it may, under situations where more than one project is to be endorsed, be used as a basis for allocating resources to the various projects. Finally, the hierarchical representation of the problem provides great flexibility and can be modified and adapted to other similar problems.

The analytic hierarchy process, then, does provide a useful methodology for improving capital investment decisions. It has been noted that the method does have its critics as well (Dyer, 1990). It must be remembered, however, that the methodology addresses only a few of the many mistakes companies make when evaluating investment proposals, namely, ignoring intangibles and qualitative factors and relying heavily on quantitative analysis. The analytic hierarchy process requires that qualitative factors - the key success factors relating company and project be delineated. If the company undertakes the appropriate effort in identifying these critical factors of the projects and tying them, not just to short-term operational objectives, but also to the organization's long-term strategic plan, the company is exercising sound investment management which should enhance the firm's well-being and long-term profitability. The analytic hierarchy process provides a consistent

methodology that helps to link strategic priorities with investment decisions, and by doing so can become an essential tool for making good capital investment decisions.

FOOTNOTES

[1]The multiple-attribute decision model is presented in Berliner and Brimson (1988), and Seed and Wagner (1988, pp. 93-95), and its discussion is included in later sections of this paper.

[2]A nine-point scale, as proposed by Saaty (1980, p. 18), can take the following form:

- A score of 1 indicates that the two criteria are equally important.
- A score of 3 indicates that one criterion is weakly more important than the other.
- A score of 5 indicates that one criterion is strongly more important than the other.
- A score of 7 indicates that one criterion is demonstrably more important than the other.
- A score of 9 indicates that one criterion is absolutely more important than the other.
- Scores of 2, 4, 6 and 8 indicate intermediate judgments.

As well, this nine-point scale is recommended for measuring the intensity of preference because it outperforms other scales (Harker and Vargas, 1987), it does not affect the final outcome of the decision process significantly even though there may be inconsistencies in the responses (Vargas, 1984), and the experience of many users found it fairly good and reliable in capturing their preferences.

[3]Two special features of the pairwise comparison matrix need to be noted. First, its diagonal elements are ONES because any criterion, when compared to itself, must be of equal importance with regard to its impact on the objective, a result which is analogous to the diagonal "ONES" of a correlation matrix. The second feature relates to the reciprocity feature: the lower half of the square matrix contains the reciprocals of the elements

of the upper half because they represent the reverse comparisons of the criteria.

[4]There are other methods which can be used for computing the local and global priority vectors (see e.g., Cogger and Yu, 1983; Jensen, 1983b). The eigenvector approach, however, is preferred because it offers the advantage of averaging the inconsistencies in judgments and responses (Harker and Vargas, 1987; Dyer, 1990), which are part of human nature. Also, software programmes, like Expert Choice, are available for eigenvector computations.

[5]In Srinivasan and Kim (1988), the analytic hierarchy process was used in evaluating investment opportunities for a multinational. In their case example, only qualitative factors were being included in assessing the preference ordering of the foreign investments. The global priority vector computed was then applied to the net present values of the foreign investments, developing the so-called absolute strategic net present value and strategic profitability index for decision making.

[6]See for example, Lang (1989), Levy and Sarnat (1986) and other management accounting or financial management textbooks.

[7]For instance, the scale for process yield might be defined as follows:

- A scalar of 0 indicates that process yield is less than 80%.
- A scalar of 1 indicates that process yield is at least 80% but less than 5%.
- A scalar of 2 indicates that process yield is at least 85% but less than 90%.
- A scalar of 3 indicates that process yield is at least 90% but less than 95%.
- A scalar of 4 indicates that process yield is at least 95% but less than 99%.
- A scalar of 5 indicates that process yield is 99% or greater.

[8]The detailed analysis and results of applying MADM to the SIT investment case are available from the authors.

[9]The responses of the pairwise comparisons and detailed results of the eigenvalue computations are available from the authors.

[10]It is assumed that the proportion of funds allocated to the project, based on the overall ranking, is adequate for its initial investment outlay. Otherwise, funds will be allocated according to the ranks of the investment projects.

[11]In the SIT case, the qualitative-nonrisk-related group of factors (QNR) has the highest priority in the capital investment decision (eigenvalue = 0.465, see Exhibit 4(a)). If, for example, SIT changes its strategy and puts greater emphasis on the quantitative-financial group of factors (QF), then overall ranking of the automation projects will change. If it can be assumed that the priority between QF and QNR switches, the resultant vector from the matrix multiplication is then [0.2681, 0.3317, 0.4002], i.e., AFMS-Z is preferred to AFMS-Y, which is preferred to AFMS-X. As noted in this discussion, analytic hierarchy process is flexible and easily adapted to sensitivity analysis.

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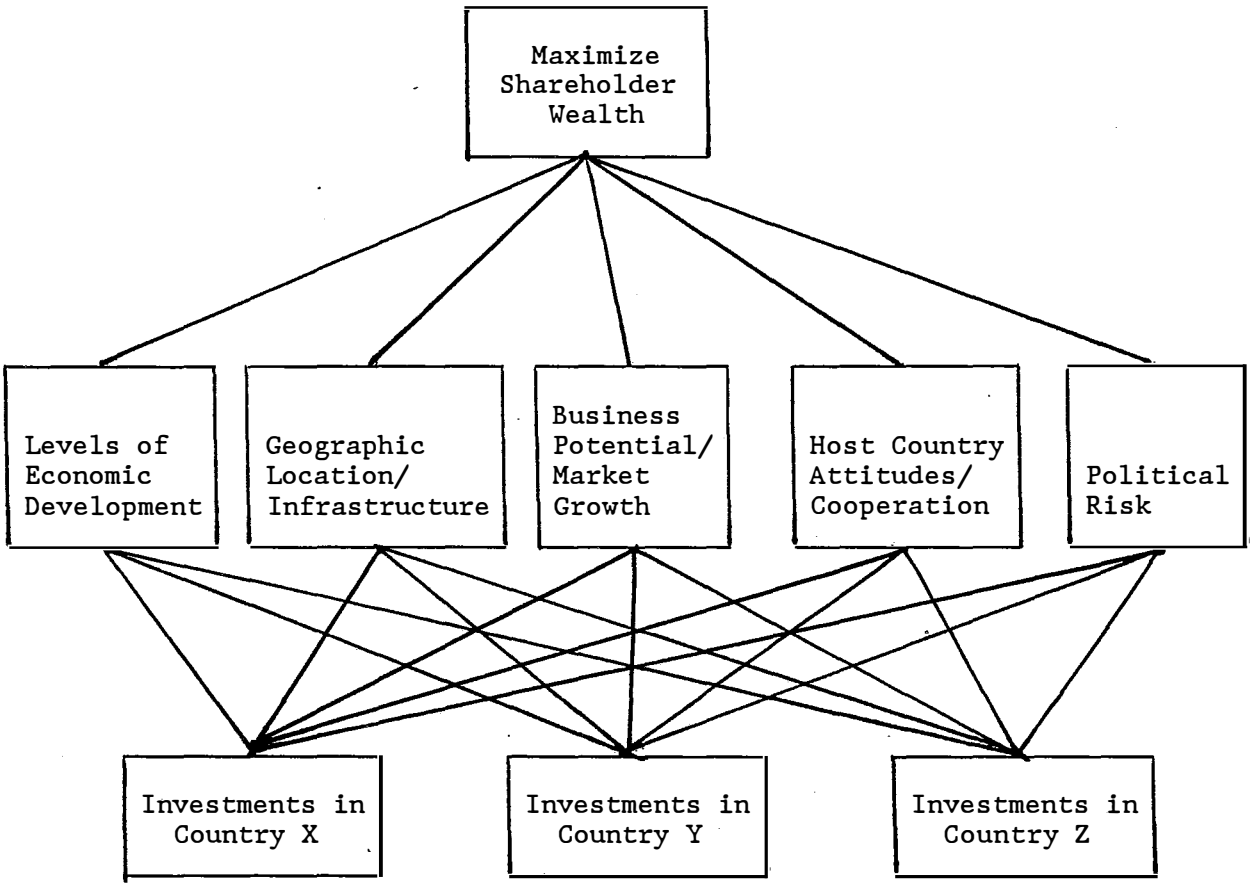


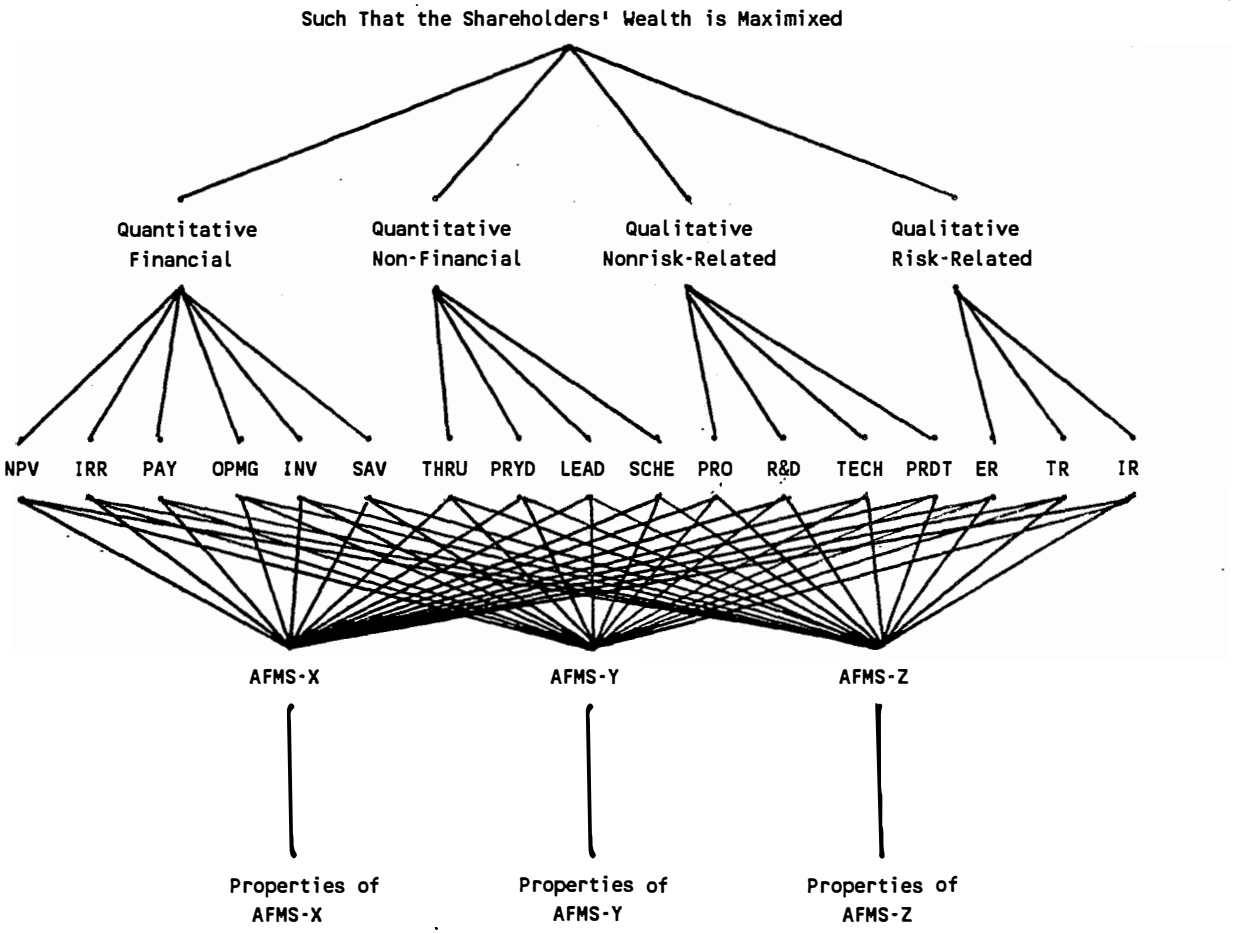
A Three-Level Hierarchy: Evaluating Foreign Investment Opportunities

Exhibit 1

	AFMS-X	AMFS-Y	AMFS-Z
(A) Quantitative-Financial			
Net present value ($million)	$ 6.9	$ 6.5	$ 7.2
Internal rate of return (%)	16.4	15.8	18.2
Payback period (years)	3.0	3.8	2.7
Annual operating margin (%)	35.2	37.5	33.8
Levels of investments ($million)	$10.2	$13.1	$12.4
Levels of savings ($million)	$22.5	$23.2	$26.0
(B) Quantitative-Nonfinancial			
Throughput time (hours)	0.31	0.27	0.35
Process yield (%)	92.0	93.5	89.0
Lead time (weeks)	13.0	10.5	11.0
Schedule attainment (%)	99.5	105.0	95.0
(C) Qualitative			
Process	Improved Capability	Improved Capability	Cost Reduction
Basic research and development	Future Technology	Innovative	Future Technology
Technology obsolescence	Improved Technology	Technology Leap Frog	Improved Technology
Product obsolescence	Improved Product	Improved Product	Improved Product

Relevant Data Regarding the Acquisition of an Automated Flexible Manufacturing System

Exhibit 2



where NPV = net present value;
IRR = internal rate of return;
PAY = payback perio;
OPMG = operating margin;
INV = levels of investments;
SAV = levels of savings;
THRU = throughtput time;
PRYD = process yield;
LEAD = lead time;
SCHE = schedule attainment;
PRO = process;
R&D = basic research and development;
TECH = technology obsolescence;
PRDT = product obsolescence;
ER = economic risk;
TR = technological risk; and
IR = implementation risk.

A Four-Level Hierarchy of Criteria, Subcriteria, Alternatives and Properties of Alternatives for the Selection of an Automated Flexible Manufacturing System

Exhibit 3

Local priority vectors:

(a) First level of criteria

EV(C) =	0.199	quantitative-financial
	0.137	quantitative-nonfinancial
	0.465	qualitative-nonrisk-related
	0.199	qualitative-risk-related

(b) Second level of subcriteria

(i) quantitative-financial

EV(F) =	0.338	NPV
	0.338	IRR
	0.162	PAY
	0.035	OPMG
	0.062	INV
	0.065	SAV.

(ii) quantitative-nonfinancial

EV(NF) =	0.083	THRU
	0.417	PRYD
	0.083	LEAD
	0.417	SCHE

(iii) qualitative-nonrisk-related

EV(NF) =	0.067	PRO
	0.079	R&D
	0.427	TECH
	0.427	PRDT

(iv) qualitiative-risk-related

EV(R) =	0.651	ER
	0.127	TR
	0.223	IR

(c) Third level of alternative per subcriteria

(i) quantitative-financial

	NPV	IRR	PAY	OPMG	INV	SAV
AFMS-X	0.323	0.172	0.131	0.258	0.109	0.122
AFMS-Y	0.089	0.102	0.793	0.637	0.582	0.230
AFMS-Z	0.588	0.726	0.076	0.105	0.309	0 648

(ii) quantitative-nonfinancial

	THUR	PRYD	LEAD	SCHE
AFMS-X	0.188	0.309	0.683	0.667
AFMS-Y	0.081	0.582	0.117	0.167
AFMS-Z	0.731	0.109	0.200	0.166

(iii) qualitative-nonrisk-related

	PRO	R&D	TECH	PRDT
AFMS-X	0.333	0.111	0.111	0.333
AFMS-Y	0.333	0.778	0.778	0.333
AFMS-Z	0.334	0.111	0.111	0.334

(iv) qualitative-risk-related

	ER	TR	IR
AFMS-X	0.297	0.258	0.333
AFMS-Y	0.163	0.637	0.333
AFMS-Z	0.540	0.105	0.334

Global priority vector:

AFMS-X	0.2702
AFMS-Y	0.4095
AFMS-Z	0.3203

Local and Global Priority Vectors Computed
Using the Analytic Hierarchy Process

APPENDIX A

Application of Multiple-Attribute Decision Model to Capital Investments

(a) Definitions of Scales of Critical Factors

(1) Quantitative-financial factors

Net present value ($M)	Internal rate of return (%)	Payback period (years)	Operating margin (%)	Levels of investments ($M)	Levels of savings ($M)	Value
< 0	< 8	> 7	< 25	> 14	< 15	0
0 to 3	8 to 12	6 to 7	25 to 30	13 to 14	15 to 18	1
3 to 5	12 to 14	5 to 6	30 to 35	12 to 13	18 to 22	2
5 to 7	14 to 16	4 to 5	35 to 40	10 to 12	22 to 23	3
7 to 9	16 to 18	2 to 4	40 to 45	8 to 10	23 to 24	4
> 9	> 18	< 2	> 45	< 8	> 24	5

(2) Quantitative-nonfinancial factors

Throughput time (hr)	Process yield (%)	Lead time (weeks)	Schedule Attainment (%)	Value
> 0.5	< 80	> 13	< 90 or > 110	0
0.4 to 0.5	80 to 85	12 to 13	90 to 110	1
0.3 to 0.4	85 to 90	11 to 12	94 to 106	2
0.2 to 0.3	90 to 95	10 to 11	98 to 102	3
0.1 to 0.2	95 to 99	8 to 10	99 to 101	4
< 0.1	> 99	< 8	100	5

(3) Qualitative factors

Process	Basic research and development	Product and technology obolescences	Value
Required for new product	Innovative major breakthrough	Technology leap frog	5
Improved process capability	Future technology requirements	Improvement	3
Cost reduction	Related to complete new product development	Alternative technology	1

(b) Computation of Priority Scores for Alternative AFMS:

Critical factors	Weight, W	Value, V	Confidence Level, CL	Score W x V x CL
AFMS-X:				
Net present value	12	3	1.0	36.0
Internal rate of return	8	4	1.0	32.0
Payback period	8	4	1.0	32.0
Annual operating margin	5	3	1.0	15.0
Levels of investments	4	3	1.0	12.0
Levels of savings	7	3	0.9	18.9
Throughput time	6	2	1.0	12.0
Process yield	7	3	0.9	18.9
Lead time	3	1	1.0	3.0
Schedule attainment	10	4	1.0	40.0
Process	7	3	0.9	18.9
Basic R & D	7	3	0.8	16.8
Technology obsolescence	8	3	0.8	19.2
Product obsolescence	8	3	0.9	21.6
			Priority score	296.3
AFMS-Y:				
Net present value	12	3	0.9	32.4
Internal rate of return	8	3	0.9	21.6
Payback period	8	4	0.9	28.8
Annual operating margin	5	3	1.0	15.0
Levels of investments	4	1	1.0	4.0
Levels of savings	7	4	1.0	28.0
Throughput time	6	3	1.0	18.0
Process yield	7	3	0.9	18.9
Lead time	3	3	1.0	9.0
Schedule attainment	10	1	1.0	10.0
Process	7	3	1.0	21.0
Basic R & D	7	5	0.9	31.5
Technology obsolescence	8	5	0.8	32.0
Product obsolescence	8	3	1.0	24.0
			Priority score	294.2
AFMS-Z:				
Net present value	12	4	1.0	48.0
Internal rate of return	8	5	1.0	40.0
Payback period	8	4	1.0	32.0
Annual operating margin	5	2	1.0	10.0
Levels of investments	4	2	1.0	8.0
Levels of savings	7	5	1.0	35.0
Throughput time	6	2	1.0	12.0
Process yield	7	2	0.9	12.6
Lead time	3	3	1.0	9.0
Schedule attainment	10	1	1.0	10.0
Process	7	1	1.0	7.0
Basic R & D	7	3	1.0	21.0
Technology obsolescence	8	3	1.0	24.0
Product obsolescence	8	3	1.0	24.0
			Priority Score	292.6

APPENDIX B

Results of Pairwise Comparisons and Eigenvector Computations for the Capital Investment Case

(a) Setting priorities among the four groups of criteria

$$\begin{array}{c} \\ QTF \\ QTNF \\ QLNR \\ QLR \end{array} \begin{array}{c} \begin{array}{cccc} QTF & QTNF & QLNR & QLR \end{array} \\ \begin{bmatrix} 1 & 2 & 1/3 & 1 \\ 1/2 & 1 & 1/2 & 1/2 \\ 3 & 2 & 1 & 3 \\ 1 & 2 & 1/3 & 1 \end{bmatrix} \end{array} \qquad EV(G) = \begin{array}{c} QTF \\ QTNF \\ QLNR \\ QLR \end{array} \begin{bmatrix} 0.199 \\ 0.137 \\ 0.465 \\ 0.199 \end{bmatrix}$$

where QTF refers to the group of quantitative-financial criteria;
QTNF refers to the group of quantitative-nonfinancial criteria;
QLNR refers to the group of qualitative-nonrisk-related criteria;
QLR refers to the group of qualitative-risk-related criteria; and
EV(G) is the resultant eigenvector.

(b) Setting priorities of criteria within each group

1. Quantitative-financial

$$\begin{array}{c} \\ NPV \\ IRR \\ PAY \\ OPMG \\ INV \\ SAV \end{array} \begin{array}{c} \begin{array}{cccccc} NPV & IRR & PAY & OPMG & INV & SAV \end{array} \\ \begin{bmatrix} 1 & 1 & 3 & 7 & 5 & 6 \\ 1 & 1 & 3 & 7 & 5 & 6 \\ 1/3 & 1/3 & 1 & 5 & 3 & 4 \\ 1/7 & 1/7 & 1/5 & 1 & 1/3 & 1/2 \\ 1/5 & 1/5 & 1/3 & 3 & 1 & 1/2 \\ 1/6 & 1/6 & 1/4 & 2 & 2 & 1 \end{bmatrix} \end{array} \qquad EV(F) = \begin{array}{c} NPV \\ IRR \\ PAY \\ OPMG \\ INV \\ SAV \end{array} \begin{bmatrix} 0.338 \\ 0.338 \\ 0.162 \\ 0.035 \\ 0.062 \\ 0.065 \end{bmatrix}$$

where EV(F) is the local priority vector for quantitative-financial criteria.

2. Quantitative-nonfinancial

$$\begin{array}{c} \\ THRU \\ PRYD \\ LEAD \\ SCHE \end{array} \begin{array}{c} \begin{array}{cccc} THRU & PRYD & LEAD & SCHE \end{array} \\ \begin{bmatrix} 1 & 1/5 & 1 & 1/5 \\ 5 & 1 & 5 & 1 \\ 1 & 1/5 & 1 & 1/5 \\ 5 & 1 & 5 & 1 \end{bmatrix} \end{array} \qquad EV(NF) = \begin{array}{c} THRU \\ PRYD \\ LEAD \\ SCHE \end{array} \begin{bmatrix} 0.083 \\ 0.417 \\ 0.083 \\ 0.417 \end{bmatrix}$$

where EV(NF) is the local priority vector for quantitative-financial criteria.

3. Quanlitative-nonrisk-related

$$\begin{array}{c} \\ PRO \\ R\&D \\ TECH \\ PRDT \end{array} \begin{array}{c} \begin{array}{cccc} PRO & R\&D & TECH & PRDT \end{array} \\ \begin{bmatrix} 1 & 1 & 1/7 & 1/7 \\ 1 & 1 & 1/5 & 1/5 \\ 7 & 5 & 1 & 1 \\ 7 & 5 & 1 & 1 \end{bmatrix} \end{array} \qquad EV(NR) = \begin{array}{c} PRO \\ R\&D \\ TECH \\ PRDT \end{array} \begin{bmatrix} 0.067 \\ 0.079 \\ 0.427 \\ 0.427 \end{bmatrix}$$

where EV(NR) is the local priority vector for quantitative-nonrisk-related criteria.

4. Quanlitative-risk-related

$$\begin{array}{c} \\ ER \\ TR \\ IR \end{array} \begin{array}{c} \begin{array}{ccc} ER & TR & IR \end{array} \\ \begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 5 & 1/3 \\ 1/5 & 3 & 1 \end{bmatrix} \end{array} \qquad EV(R) = \begin{array}{c} ER \\ TR \\ IR \end{array} \begin{bmatrix} 0.651 \\ 0.127 \\ 0.223 \end{bmatrix}$$

where EV(R) is the local priority vector for qualitative-risk-related criteria.

(c) Evaluation of alternative AFMS per criteria

1. NPV

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 4 & 1/2 \\ 1/4 & 1 & 1/6 \\ 2 & 6 & 1 \end{bmatrix} \end{array}$$

2. IRR

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 2 & 1/5 \\ 1/2 & 1 & 1/6 \\ 5 & 6 & 1 \end{bmatrix} \end{array}$$

3. PAY

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1/7 & 2 \\ 7 & 1 & 9 \\ 1/2 & 1/9 & 1 \end{bmatrix} \end{array}$$

4. OPMG

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1/3 & 3 \\ 3 & 1 & 5 \\ 1/3 & 1/5 & 1 \end{bmatrix} \end{array}$$

5. INV

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1/5 & 1/3 \\ 5 & 1 & 2 \\ 3 & 1/2 & 1 \end{bmatrix} \end{array}$$

6. SAV

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1/2 & 1/5 \\ 2 & 1 & 1/3 \\ 5 & 3 & 1 \end{bmatrix} \end{array}$$

7. THRU

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 3 & 1/5 \\ 1/3 & 1 & 1/7 \\ 5 & 7 & 1 \end{bmatrix} \end{array}$$

8. PRYD

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1/2 & 3 \\ 2 & 1 & 5 \\ 1/3 & 1/5 & 1 \end{bmatrix} \end{array}$$

9. LEAD

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 5 & 4 \\ 1/5 & 1 & 1/2 \\ 1/4 & 2 & 1 \end{bmatrix} \end{array}$$

10. SCHE

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 4 & 4 \\ 1/4 & 1 & 1 \\ 1/4 & 1 & 1 \end{bmatrix} \end{array}$$

11. PRO

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \end{array}$$

12. R&D

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1/7 & 1 \\ 7 & 1 & 7 \\ 1 & 1/7 & 1 \end{bmatrix} \end{array}$$

13. TECH

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1/7 & 1 \\ 7 & 1 & 7 \\ 1 & 1/7 & 1 \end{bmatrix} \end{array}$$

14. PRDT

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \end{array}$$

15. ER

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 2 & 1/2 \\ 1/2 & 1 & 1/3 \\ 2 & 3 & 1 \end{bmatrix} \end{array}$$

16. TR

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1/3 & 3 \\ 3 & 1 & 5 \\ 1/3 & 1/5 & 1 \end{bmatrix} \end{array}$$

17. IR

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{cccccc} EV1 & EV2 & EV3 & EV4 & EV5 & EV6 \end{array} \\ \begin{bmatrix} 0.323 & 0.172 & 0.131 & 0.258 & 0.109 & 0.122 \\ 0.089 & 0.102 & 0.793 & 0.637 & 0.582 & 0.230 \\ 0.588 & 0.726 & 0.076 & 0.105 & 0.309 & 0.648 \end{bmatrix} \end{array} \qquad \begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{cccc} EV7 & EV8 & EV9 & EV10 \end{array} \\ \begin{bmatrix} 0.188 & 0.309 & 0.683 & 0.667 \\ 0.081 & 0.582 & 0.117 & 0.167 \\ 0.731 & 0.109 & 0.200 & 0.166 \end{bmatrix} \end{array}$$

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{cccc} EV11 & EV12 & EV13 & EV14 \end{array} \\ \begin{bmatrix} 0.333 & 0.111 & 0.111 & 0.333 \\ 0.333 & 0.778 & 0.778 & 0.333 \\ 0.334 & 0.111 & 0.111 & 0.334 \end{bmatrix} \end{array} \qquad \begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} EV15 & EV16 & EV17 \end{array} \\ \begin{bmatrix} 0.297 & 0.258 & 0.333 \\ 0.163 & 0.637 & 0.333 \\ 0.540 & 0.105 & 0.334 \end{bmatrix} \end{array}$$

where X is AFMS-X;
Y is AFMS-Y;
Z is AFMS-Z; and
EV*i* is the local priority vector of the three automated flexible manufacturing systems per *i*th criterion.

(d) Weighting of local priority vectors

1. Relative ranking of alternative AFMS based on quantitative-financial factors, RR(F)

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{cccccc} EV1 & EV2 & EV3 & EV4 & EV5 & EV6 \end{array} \\ \begin{bmatrix} 0.323 & 0.172 & 0.131 & 0.258 & 0.109 & 0.122 \\ 0.089 & 0.102 & 0.793 & 0.637 & 0.582 & 0.230 \\ 0.588 & 0.726 & 0.076 & 0.105 & 0.309 & 0.648 \end{bmatrix} \end{array} \begin{array}{c} EV(F) \\ \begin{bmatrix} 0.338 \\ 0.338 \\ 0.162 \\ 0.035 \\ 0.062 \\ 0.065 \end{bmatrix} \end{array} = \begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} RR(F) \\ \begin{bmatrix} 0.2123 \\ 0.2664 \\ 0.5213 \end{bmatrix} \end{array}$$

2. Relative ranking of alternative AFMS based on quantitative-nonfinancial factors, RR(NF)

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{cccc} EV7 & EV8 & EV9 & EV10 \end{array} \\ \begin{bmatrix} 0.188 & 0.309 & 0.683 & 0.667 \\ 0.081 & 0.582 & 0.117 & 0.167 \\ 0.731 & 0.109 & 0.200 & 0.166 \end{bmatrix} \end{array} \begin{array}{c} EV(NF) \\ \begin{bmatrix} 0.083 \\ 0.417 \\ 0.083 \\ 0.417 \end{bmatrix} \end{array} = \begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} RR(NF) \\ \begin{bmatrix} 0.4793 \\ 0.3288 \\ 0.1919 \end{bmatrix} \end{array}$$

3. Relative ranking of alternative AFMS based on qualitative-nonrisk-related factors, RR(NR)

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{cccc} EV11 & EV12 & EV13 & EV14 \end{array} \\ \begin{bmatrix} 0.333 & 0.111 & 0.111 & 0.333 \\ 0.333 & 0.778 & 0.778 & 0.333 \\ 0.334 & 0.111 & 0.111 & 0.334 \end{bmatrix} \end{array} \begin{array}{c} EV(NR) \\ \begin{bmatrix} 0.067 \\ 0.079 \\ 0.427 \\ 0.427 \end{bmatrix} \end{array} = \begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} RR(NR) \\ \begin{bmatrix} 0.2207 \\ 0.5582 \\ 0.2211 \end{bmatrix} \end{array}$$

4. Relative ranking of alternative AFMS based on qualitative-risk-related factors, RR(NR)

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} EV15 & EV16 & EV17 \end{array} \\ \begin{bmatrix} 0.297 & 0.258 & 0.333 \\ 0.163 & 0.637 & 0.333 \\ 0.540 & 0.105 & 0.334 \end{bmatrix} \end{array} \begin{array}{c} EV(R) \\ \begin{bmatrix} 0.651 \\ 0.127 \\ 0.222 \end{bmatrix} \end{array} = \begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} RR(R) \\ \begin{bmatrix} 0.3000 \\ 0.2609 \\ 0.4391 \end{bmatrix} \end{array}$$

5. Global priority of alternative AFMS based on all 17 factors, GLOBAL

$$
\begin{array}{c}
 \\ X \\ Y \\ Z
\end{array}
\begin{array}{c}
\begin{array}{cccc} RR(F) & RR(NF) & RR(NR) & RR(R) \end{array} \\
\begin{bmatrix} 0.2123 & 0.4793 & 0.2207 & 0.3000 \\ 0.2664 & 0.3288 & 0.5582 & 0.2609 \\ 0.5213 & 0.1919 & 0.2211 & 0.4391 \end{bmatrix}
\end{array}
\begin{array}{c}
EV(G) \\
\begin{bmatrix} 0.199 \\ 0.137 \\ 0.465 \\ 0.199 \end{bmatrix}
\end{array}
=
\begin{array}{c}
 \\ X \\ Y \\ Z
\end{array}
\begin{array}{c}
GLOBAL \\
\begin{bmatrix} 0.2702 \\ 0.4095 \\ 0.3203 \end{bmatrix}
\end{array}
$$

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