工場自動化 事業의 投資 正當性 分析, 經濟性 分析만으로 充分한가?

Capital Budgeting Methods Are Not Enough : Justification of Factory Automation Projects

박 용 태(한국과학기술연구원 정책·기획본부 선임연구원)

October 20, 1992

Capital Budgeting Methods Are Not Enough: Justification of Automation Projects

by

Yong-Tae Park

Senior Research Fellow,

Science and Technology Policy Institute (STEPI)/
Korea Institute of Science and Technology (KIST)

ABSTRACT

To date, the implementation and adoption of new manufacturing technologies has been retarded despite their technical advances and strategic virtues such as flexibility and synergy effect. This phenomenon is partly attributable to the lack of commensurate development and widespread dissemination of adequate selection and justification procedures. Many strategically vital automation projects have been rejected and/or seemingly promising proposals have turned out to be fiascos since the justification process has been solely based on the traditional capital budgeting or engineering economy methods. As the degree of system automation/integration increases, a variety of benefit/cost attributes, both quantitative and qualitative, should be taken into account and more comprehensive and analytic justification methods should be applied in the justification process.

This paper points out the distinct characteristics of advanced technologies and presents an illustrative set of procedures that can be used in the justification process. It outlines the algorithmic structure of each procedure and also describes the advantages/disadvantages of each procedure and the conditions under which it is most appropriate to employ.

The selection of appropriate justification technique is situation-specific. In general, it is recommended that more complex and sophisticated procedures be used as the degree of integration increases. Nonetheless, traditional procedures may be used as well to make in-depth analyses of the local impact.

I. Introduction

Recently, the automation of factories has received a growing attention from practitioners and academicians alike. The main driving force of this phenomenon is due to the potential capability of modern technologies that may enhance the competitiveness of manufacturing industry. Despite the ardent advocacy of proponents, however, the actual implementation and adoption of factory automation in industry has lagged the technical and engineering advances. While manufacturing technologies have become increasingly sophisticated in its ability to provide flexibility and strategic benefits to the prospective users, application of those technologies by firms have not been so prevalent. Although the main reason of this stagnation is attributable to the burden of the front-end capital investment, part of it is grounded on the managerial negligence and misconception. That is, one of the obstacles to automating factories is not due to the absence of proper technologies but due to the lack of commensurate development and widespread dissemination of adequate justification procedures.

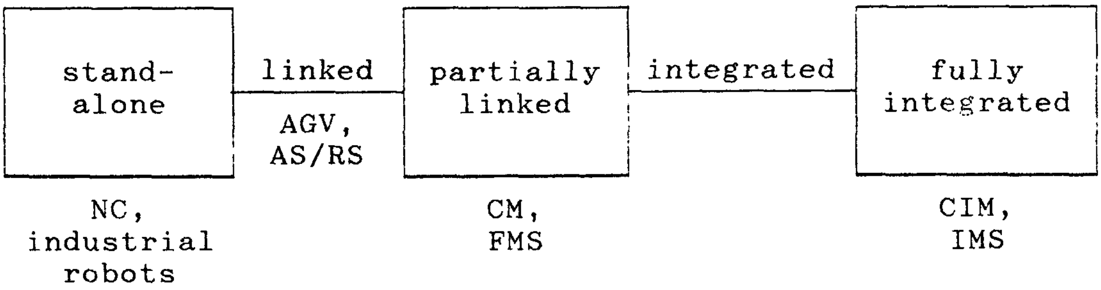
In principle, the rationale for selecting technological alternative(s) is universal in that the most promising one, in terms of predetermined criteria, is chosen. However, advanced technologies such as factory automation are characterized by several distinct properties that are not applicable to traditional ones. Accordingly, the selection and justification process of new technologies needs to take considerably different approaches, compared to those for conventional technologies.

This paper examines distinct characteristics of advanced technologies and suggests a selective set of procedures for the justification of those technologies. It also describes the advantages/disadvantages of each procedure and the conditions under which it is most appropriate to employ. It should be pointed out, however, that the list of the procedures reviewed here is by no means exhaustive. The spirit of this paper is rather exploratory in that it attempts to raise some critical questions and present illustrative methodologies to cope with those questions.

II. Characteristics of Advanced Manufacturing Technologies

Advanced manufacturing technologies for factory automation span a continuum with respect to the degree of integration, from stand-alone equipment to full computer-integrated manufacturing (CIM). Typically, a mere replacement of conventional facilities by numerically controlled (NC) machines and/or industrial robots belong to the stand-alone category. Often, the missing link among these facilities results in the so-called "islands of automation" situation in which automation projects are implemented independently without considering the inter-departmental connectivity and, consequently, local economy leads to global diseconomy. When the stand-alone equipments are linked together, along with automated guided vehicles (AGVs) and automated storage/retrieval systems (AS/RSs), an intermediate level of integration is achieved. Cellular manufacturing (CM) or flexible manufacturing system (FMS) are typical forms falling into this category. If the whole manufacturing process, from design to inspection, is computerized and operationalized in a consistent fashion, the factory is considered to be fully integrated, commonly known as CIM. Lately, a revolutionary project, construction of an intelligent manufacturing system (IMS), has been launched on by pioneering researchers. Although the progress is at an infant stage and, thus, the concrete structure and operational mechanism of the system is opaque, it aims to integrate the complete set of activities of enterprises, R&D, production, and marketing, through a host computer of strategic information system (see Figure 1).

Figure 1: Degree of Integration of Manufacturing System



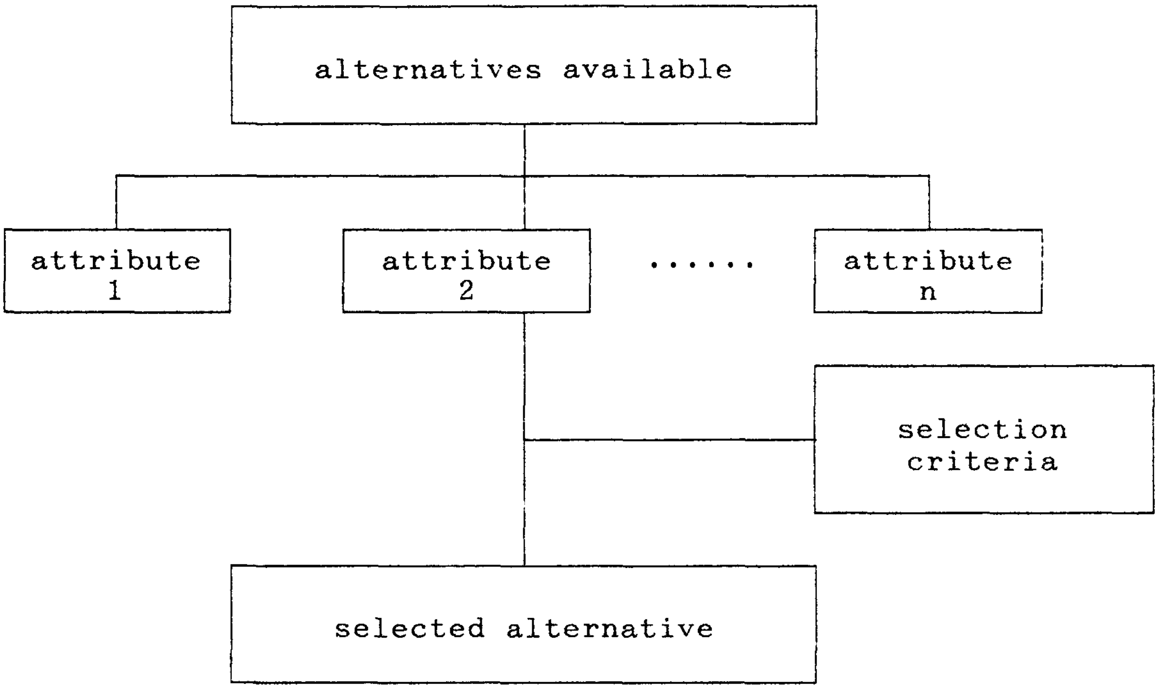
Advanced manufacturing technologies are characterized by the intrinsic obscurity of the trade-off analyses. Many of the potential benefits/costs of them are hard to identify and grasp in monetary terms since they tend to lie in rather nebulous, strategic areas. The risk and uncertainty of the gigantic initial investment becomes higher as the degree of automation/integration increases. Among others, the following three characteristics make the justification process more complex than that of traditional capital investments. First, the multi-attribute property is highlighted in case of advanced technologies. Frequently, mutually-conflicting attributes coexist and a set of relative gains may be attained only at the expense of some comparative losses. In addition, the risk involved in the acquisition of the expensive technology could be substantial not only in a financial sense but also in an organizational sense since the entire infrastructure of the manufacturing system needs to be changed to actualize the potential benefits. Second, advanced automation technologies are much more flexible than conventional ones. Previous types of capital investments were based on the objective of enhancing efficiency of the system, i.e., higher volume and lower unit cost. However, today's flexible automation emphasizes on the effectiveness of the system, the responsiveness to market needs. The flexibility in this context, defined as the capability to move quickly from one state to another or the capability to adapt to changes, is not readily captured in simple monetary value. Third, the synergy effect, accrued as the degree of integration of the system increases, can be far more significant than the normal cost savings. If the benefits reaped are synergistic, the synergy benefit should be discriminated from the direct benefit and measured separately. This property, however, is not amenable to accurate estimation.

Unfortunately, the characteristics depicted above have frequently been neglected in the justification process and many strategically vital automation proposals have been rejected. Conversely, a number of financially justifiable proposals have turned out to be fiascos since the strategic benefits of them have not been fully exploited. Previously developed methods may be still useful in addressing subsets of factors, but may fall short in comprehensive analyses. Hence, more synthetic and systematic methodologies are required as the degree of automation/integration increases.

III. Framework of the Selection and Justification Process

In essence, the selection and justification process consists of three major decision factors, alternatives, attributes, and selection criteria. Alternatives of course represent the set of possible choices proposed. Attributes refer to the benefit/cost factors of those alternatives. Selection criteria mean the standards or guidelines by which comparison and assessment of the alternatives is made. Hence, selection procedure can be summarized as a decision making process in which attributes of the proposed alternatives are analyzed and the most promising alternative, in terms of the given criteria, is chosen among multiple candidates available (see Figure 2).

Figure 2: Framework of the Selection Process



In automating factory, various alternatives are possible depending on the nature, objectives, and financial capabilities of firms. Even stand-alone equipments may vary in terms of their function and specification. Integration of the system entails further diversity depending on the degree/direction of automation. This multiplicity of implementation paths usually results in a variety of proposals: (1) radical vs incremental, (2) forward vs backward, and (3) complete vs partial automation approaches.

Attributes can be classified into several categories. The most popular classifications include (1) tangible and intangible and (2) strategic and operational attributes. Tangible attributes indicate those factors that can be accurately estimated and easily quantified whereas intangible attributes denote those factors that are rather implicit and qualitative and, thus, hard to quantify. Similarly, strategic attributes refer to the long-term outlook for a firm which address such issues as overall competitiveness, ability to adjust to market changes, or lower exposure to labor unrest. Operational attributes, on the other hand, are associated with short-term effects such as reduction in lead time, decrease in work-in-process (WIP) inventory, improved quality, or efficient machine utilization.

Selection criteria provide the bases for comparative evaluation. Ideally, the "principle of dominance" can be applied as the basic rule for decision making. That is, if one alternative has values which are at least as good as those of another alternative with respect to all measures, and if it has one or more values that are better, then the former "dominates" the latter and the latter can be eliminated from further consideration. Obviously, this principle is least controversial and can be easily imposed. In practice, however, it would have a very limited degree of applicability since few alternatives will be completely dominated unless the number of attributes is extremely small. Hence, the selection procedure needs to construct logical and consistent selection criteria by which competitive alternatives are comparatively evaluated.

IV. Justification Procedures

Broadly, a variety of selection/justification procedures have been proposed in the literature (e.g., Keeney and Raiffa,1976 and Chankong and Haimes,1983). Many of those techniques, however, are insufficient or inappropriate since they are designed to handle investment in conventional manufacturing systems or non-manufacturing fields.

IV.1 Procedures for Local Automation

When the investment proposal is merely to purchase a stand-alone equipment in a particular department/work center, the impact of the proposal may be readily predictable and the benefit/cost factors can be converted into a single attribute. The attribute tends to be easily quantified and is usually expressed in a monetary value.

Traditional capital budgeting and engineering economy methodologies can be suitable choices for this case. The cash flow of each proposal is calculated over the planning time horizon and the one that yields the most economic (financial) benefit is chosen. Payback period method, net present value (NPV) method, internal rate of return (IRR) method, return on investment (ROI) method, MAPI method, and benefit/cost ratio method are typical procedures belonging to this category.

To date, the overwhelming majority of firms have used the traditional justification methods to analyze the desirability of automation investments. The main advantage of these procedures is their simplicity and clarity. The critical question, however, is how to incorporate non-financial, qualitative factors into the procedure.

IV.2 Procedures for Global Automation

As the size of the project is enlarged and the scope of the automation is widened, multiple attributes should be included in the justification process since intangible and qualitative factors, as well as tangible and quantitative factors, are incorporated. The core part of the process, then, is the procedural scheme to cope with multiple attributes that are likely to be incompatible and/or mutually-conflicting one another. Broadly, the following three ways are suggested. First, simultaneous procedures consider all attributes at the same time in an aggregate fashion. Second, hierarchical procedures decompose the whole problem and/or attributes in a hierarchical manner based on the structure of the problem. Third, sequential procedures divide attributes into several groups and sequentially evaluate alternatives with respect to each group of attributes.

(1) Simultaneous procedures: Aggregate function approach

Simultaneously procedures first identify attributes regardless of the order/priority of them. Then, alternatives are comparatively assessed based on an aggregate value which indicates the overall performance of each alternative with respect to all attributes. Thus, the term "simultaneous" means that all attributes are considered and the overall performance is measured at the same time. Among several procedures, the aggregate function approach may represent this category.

In the aggregate function approach, a linear additive aggregate function which contains all attributes as variables of the function is formulated and the alternative which exhibits the best overall value, either maximum or minimum, is selected. In order to resolve the incompatibility of measures among attributes, the relative performance, with respect to each attribute, of alternatives is expressed in a dimensionless value such as "score". The score can assume either binary values (0-1) or multi-point scale values (e.g., 1-5 if a five-point scale is applied). In a binary value system, with respect to each attribute, an alternative takes 1 if it qualifies but 0 if it does not. In a multi-point scale system, for each attribute, an alternative takes one of the possible values depending on the degree to which it meets the criteria. Further, to each attribute, the decision maker may assign importance "weight" which becomes the coefficient of the variable in the aggregate function. The underlying assumption is that the decision maker can order the strength of preference among attributes. Thus, the formulation of the aggregate function is stated as:

$$TS_j = \Sigma_{i=1}^{n} w_i s_{ij}$$

where

TS_j = total score for alternative j;
w_i = weight for attribute i that reflect the relative importance of the attribute;
s_{ij} = subscore for alternative j with respect to attribute i.

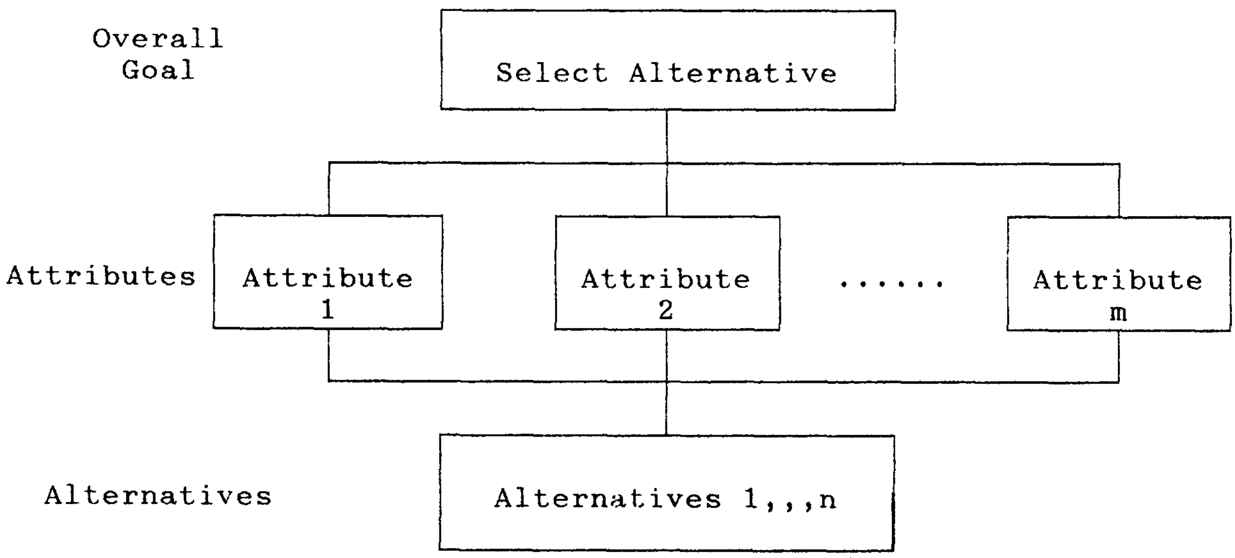
The aggregate function approach would be one of the easiest one to apply. Its validity, however, might be limited due to the following drawbacks. First, in many cases, it is doubtful to ascertain the linearity of the function. Second, it is difficult to determine the relative importance of each attribute in a "numerical" way. These difficulties become more serious as the number of attributes increases. Third, since attributes are lumped together into an aggregate function, underlying factors get obscured. That is, it is possible that two alternatives are identical with respect to the aggregate value, but differ considerably with respect to individual attributes. Fourth, there is a risk of ignoring interactions among attributes. The results could be misleading if the assumption of independence among attributes is violated.

(2) Hierarchical procedures: Analytical Hierarchy Process (AHP)

When the multiple attributes are included in the justification process, another way to reduce the complexity is to decompose the whole problem and/or the population of attribute in a hierarchical fashion. That is, based on the structural nature of the proposal, more strategic objectives or attributes are placed on the upper layers and rather technical ones are put on the lower layers in the hierarchy. Then, detailed analyses are made layer-wise and the respective results are synthesized to compute the overall performance.

The AHP approach, developed by Saaty (1980), can be exemplified as the typical one belonging to this category. The first step in the AHP is to develop a graphical representation of the problem in terms of the overall goal, attributes, and the alternatives. Such a graph depicts the hierarchy for the problem (see Figure 3). It should be

Figure 3: Decomposition of the Problem into a Hierarchy



mentioned that attributes, located at the middle level, can be further divided into sub-levels according to their hierarchical priorities. Strategic attributes may be put at the top level, tactical attributes at the intermediate level, while operational attributes at the low level. The second step, "pairwise" comparisons are the fundamental building blocks of the AHP. For each attribute, the preference of decision maker is determined between two alternatives (pairwise) at a time. The relative preference is expressed in scores. For instance, if the preference rating for alternative A when compared to alternative B is 2, the rating for B against A is simply the reciprocal, 1/2. This process is repeated until all the possible combinations of the pairwise comparisons are made, i.e., n(n-1)/2 judgements if there are n alternatives, and the results are summarized in the normalized comparison matrix. By the same token, matrices are developed for other attributes:

$$A_t = \left| \quad \ldots\ a(i,j)\ \ldots \quad \right|$$

= normalized matrix for attribute t

where, a(i,j) = rating for alternative i against alternative j with respect to attribute t,
a(i,j) = 1 / a(j,i).

A notable feature of the AHP is that the so-called "consistency ratio (CR)" is computed to guarantee the consistency of subject judgements on the preference, i.e., to check whether a(i,j) = a(i,k) x a(k,j) for all i,j,k. Ideally, the critical ratio is 0 if a "perfect" consistency is acquired. In practice, however, if the ratio exceeds a predetermined threshold level and, therefore, the degree of discrepancy is unacceptable, the pairwise comparison process should be revised. Once the critical ratio test is completed, the average of the elements in each row of the normalized matrix is computed. These averages, in turn, provide an estimate of the relative priorities among alternatives with respect to each attribute. The third step is to determine the priorities among attributes. Note that attributes are located at the higher level than alternatives in the hierarchial structure. Analogous pairwise comparisons are made between attributes to identify the priority rankings. The final step is to combine previous results, pairwise comparison between alternatives for each attribute and pairwise comparisons between attributes, to obtain the overall priority among alternatives.

The AHP seems to be a useful procedure in dealing with a large-scale, complex project. First, it allows the incorporation of various levels of expertise into an integrated framework. Thus, upper level management and lower level engineering experts can contribute in their respective areas of knowledge and responsibility. Second, it is flexible in that the overall structure is divided into several hierarchical modules. In order to execute the process, however, an interactive communication channel should be established between participating decision makers.

(3) Sequential procedures: Sequential elimination procedure

In order to facilitate the analysis of the complex projects, the justification process can be designed in a sequential manner. In other words, the whole process is divided into several phases and, at each phase, good alternatives are selected or bad alternatives are filtered out. The sequential elimination procedure may be a representative of this category.

In this approach, all attributes are partitioned into several sub-groups based on some characteristics they possess. It should be noted that the characteristics may not be related to their relative importance/priority. Instead, the inherent features of interest (i.e., quantitative or qualitative, static or dynamic, deterministic or stochastic, etc.) can be the relevant criteria. At the outset, alternatives are comparatively evaluated with respect to the first set of attributes and either eliminated or retained. Typically, the decision maker sets up standards to be applied to the values on certain attributes. Then, either conjunctive ("and") or disjunctive ("or") form of filtering criteria are imposed. Often, a combination of both forms can be practical. To illustrate, one type of the pass/fail criterion could be "retain if $A_1 \geq C_1$ and $A_2 \leq C_2$ or $C_3 \leq A_3 \leq C_4$." The process is repeated until all the sets of attributes are exhausted.

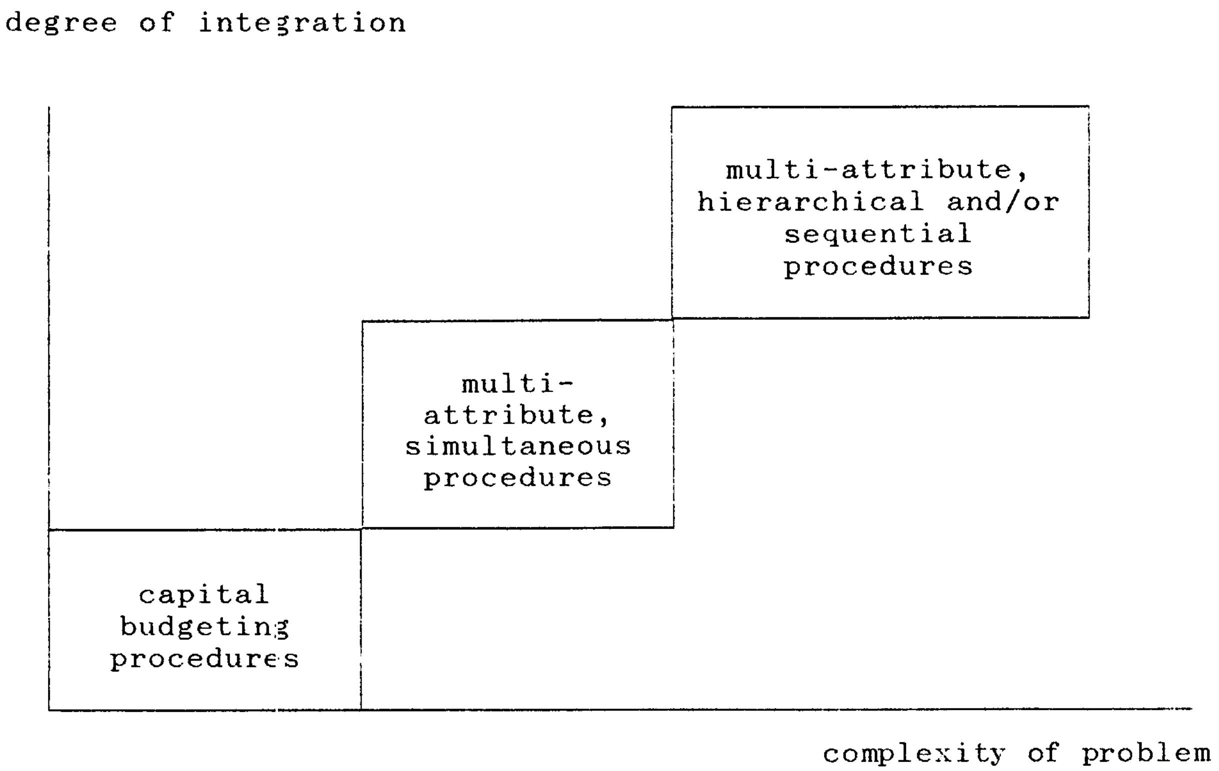
In an extensive selection project, this approach could be an appropriate choice since it facilitates the execution of the project. The whole process is separated into several stages and each stage focuses on a limited set of attributes. Further, the approach is comprehensive in that no relevant measure will be excluded. However, it is possible that the process ends up with multiple alternatives that pass all criteria.

V. Conclusions

The use of an adequate evaluation scheme is indispensable to justifying and selecting competitive proposals in implementing automation projects. In particular, the characteristics of advanced manufacturing technologies such as multi-attribute nature, flexibility, and synergy effect should be incorporated into the selection process.

Some procedures have been briefly reviewed in this paper. The application of the appropriate procedure is situation-specific. In general, however, it is recommended that more complex and sophisticated procedures be used as the degree of system integration, i.e., the size of the automation project, increases (see Figure 4). Nonetheless, traditional procedures such as capital budgeting and engineering economy tools may be used as well to make in-depth analyses of the local impact. Further, as suggested by Keen (1981), a two-stage approach can be adopted to reduce the complexity of the process. In the "pilot" stage, a small-scale system with limited functional capability is constructed and a preliminary assessment is conducted. If the pilot stage was successful, a full-fledged evaluation is made in the "build" stage, with the development of a complete system.

Figure 4: General Guideline for Selection of Procedures



REFERENCES

Arbel,A. "Performance Evaluation of Flexible Manufacturing Systems." IEEE Transactions on Systems, Man, and Cybernetics, Vol.SMC-14, No.4 (1984).

Chankong,V. and Haimes,Y. Multiobjective Decision Making: Theory and Methodology. North-Holland, New York, 1983.

Elmaghraby,S. The Design of Production System. Reinhild Publishing Corporation, New York, 1966.

Gass,S. "Decision-Aiding Models : Validation, Assessment, and Related Issues for Policy Analysis." Operations Research, Vol.31, No.4 (1983).

Gerwin,D. "Do's and Don'ts of Computerized Manufacture." Harvard Business Review, March-April, 1982.

Gongaware,T. and Ham,I. "Cluster Analysis Application for Group Technology Manufacturing Systems" Proceedings of Ninth North American Metal Working Research Conference, Dearborn, Michigan (1981).

Ignizio,P. Goal Programming and Extensions. D.C. Heath Books, Lexington, 1976.

Kamenetzky,R. "The Relationship between the Analytic Hierarchy Process and the Additive Value Function." Decision Sciences, Vol.13 (1982).

Keeney,R. and Raiffa,H. Decisions with Multiple Objectives: Preferences and Value Tradeoffs. Wiley, New York, 1976.

Meredith,J. and Suresh,N. "Justification Techniques for Advanced Manufacturing Technologies" International Journal of Production Research, Vol.24, No.4 (1986).

Nutt,P. "Comparing Methods for Weighting Decision Criteria." OMEGA, Vol.8, No.2 (1980).

Saaty, L. The Analytical Hierarchy Process. McGraw-Hill, New York, 1980.

Slack,N. "Flexibility as a Manufacturing Objective." International Journal of Operations and Production Management, Vol.3, No.3 (1983).

Tombari,A. "To Buy or Not to Buy? Weighing Capital Investments." Production Engineering, March (1978).

Troxier,J. and Blank,L. "A Comprehensive Methodology for Manufacturing System Evaluation and Comparison." Journal of Manufacturing Systems, Vol.8, No.3 (1988).

Wabalickis,R. "Justification of FMS with the Analytic Hierarchy Process." Journal of Manufacturing Systems, Vol.7, No.3 (1987).

Whybark,C. "Multiple Criteria Classification Using the Bifurcation Procedure" Discussion paper # 420, Graduate School of Business, Indiana University (1989).

Zahedi,F. "The Analytic Hierarchy Process - A Survey of the Method and its Applications." Interface, Vol.16, No.4 (1986)