Capital Budgeting Methods Are Not Enough : Justification of Automation Projects

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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.

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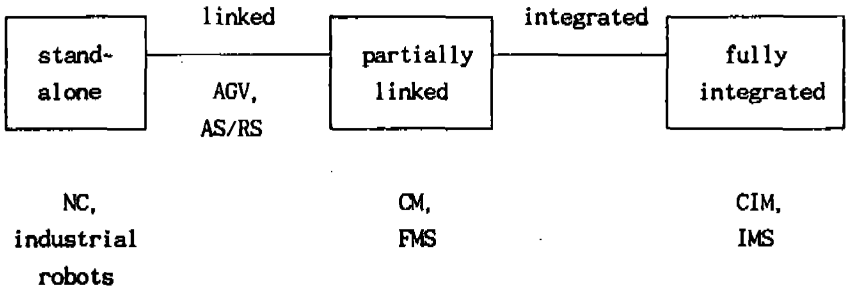
This paper examines distinct characteristics of advanced technologies and suggests a selective set of procedures for the justification of those technologies. It also describes the advantages/disadvantages of each procedure and the conditions under which it is most appropriate to employ. It should be 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



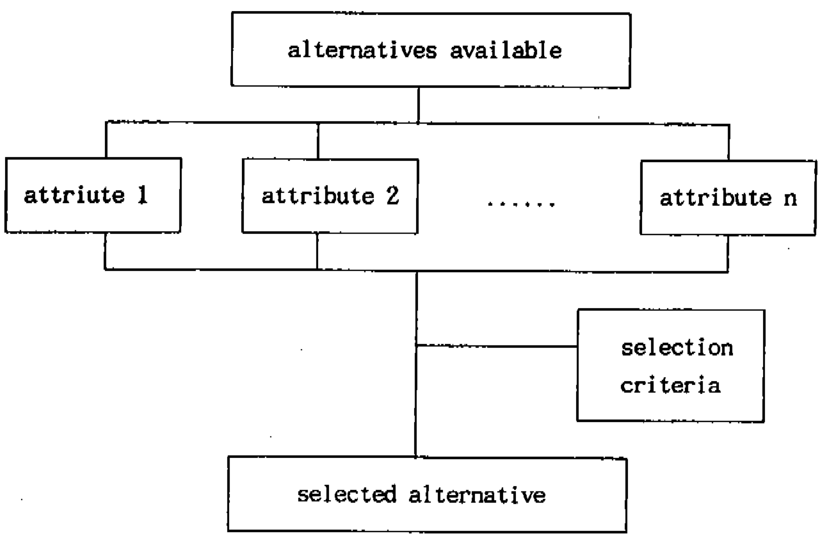
Advanced manufacturing technologies are characterized by the intrinsic obscurity of the trade-off analyses. Many of the potential benefits/costs of them are hard to identify and grasp in monetary terms since they tend to lie in rather nebulous, strategic areas. The risk and uncertainty of the gigantic 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:

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

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.

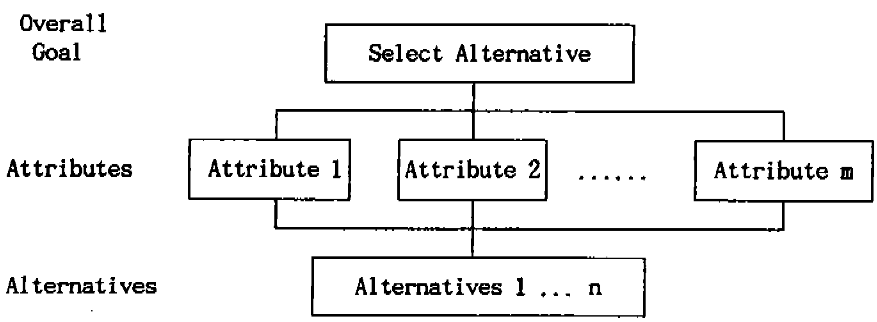
The aggregate function approach would be one of the easiest one to apply. Its validity, however, might be limited due to the following drawbacks. First, in many cases, it is doubtful to ascertain the linearity of the function. Second, it is difficult to determine the relative importance of each attribute 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 mentioned that attributes,

Figure 3: Decomposition of the Problem into a Hierarchy



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:

$$A_t = \begin{vmatrix} & \\ \ldots\ a(i,j)\ \ldots \\ & \end{vmatrix}$$

= 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 $A1 \geq C1$ and $A2 \leq C2$ or $C3 \leq A3 \leq C4$." The process is repeated until all the sets of attributes are exhausted.

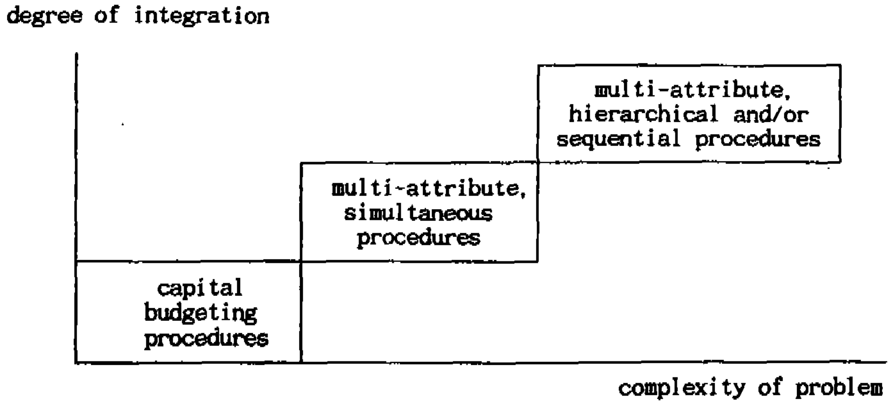
In an extensive selection project, this approach could be an appropriate choice since it facilitates the execution of the project. The whole process is separated into several stages and each stage focuses on a limited set of attributes. Further, the approach is comprehensive in that no relevant measure 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



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국문 요약:

최근, 시장환경 및 생산구조의 변화에 따라 이른바 첨단생산기술(advanced manufacturing technologies)의 개발과 활용이 산업계 및 학계의 큰 관심을 끌고 있다. 그러나 첨단생산기술의 급속한 기술적 발전과 전략적 가치의 증가에도 불구하고 산업에의 확산은 상대적으로 부진한 현실이다. 이러한 현상은 물론 초기 투자의 財源調達 문제에 基因한다고 할 수 있지만 일차적으로는 적절한 代案을 선정하고 투자의 정당성을 분석하는 방법론의 미비도 그 원인으로 지적되고 있다. 本稿는 전통적(conventional) 생산기술과 비교한 첨단생산기술의 특성에 대한 이해를 기초로, 새로운 기술대안들을 비교분석하는 구체적인 기법의 개발에 관한 접근의 방향성과 개념의 틀(framework)을 제시하는 데 그 목적이 있다.

첨단생산기술의 대안선정과 정당성분석은 다음의 몇가지 특성을 지니고 있다. 첫째, 투자대안의 屬性이 다양하며(multi-attribute) 각각의 속성이 相衝的(conflicting)일 수 있다. 둘째, 기술대안들의 잠재적 기능이 생산체제의 伸縮性과 柔軟性(flexible)의 제고를 강조하고 있다. 세째, 개별기술의 통합을 통해 시스템 전체의 상승효과(synergy effect)를 추구하고 있다. 따라서 이러한 특성에 대한 인식을 토대로 定量的이고 戰略的인 장·단점에 대한 고려를 포함하는 종합적이고 객관적인 분석의 틀과 기법이 사용되지 않으면 첨단생산기술의 성공적인 도입과 활용은 기대하기 어려운 것이다.

새로운 생산기술의 도입이 공정의 부분적 개선을 위한 소규모 투자일 경우에는 경제성의 분석을 위해서는 전통적인 재무관리(capital budgeting) 기법들이 이용될 수 있고 직접적인 공정개선의 효과분석을 위해서는 시뮬레이션을 적용하는 것이 바람직하다고 할 수 있다.

그러나 기술대안의 규모가 크고 따라서 그 파급효과가 전체공정으로 확산되는 대규모 사업일 경우에는 다양한 장·단점들을 고려하는 종합적인 접근의 틀이 필요하게 된다. 이러한 방법들을 크게 세가지 형태로 나누어 보면 (1) 모든 대안들에 대해, 모든 요소들에 관한 비교분석을 동시에 실시하는 同時的 접근(simultaneous approach), (2) 대안 또는 요소들을 그 성격에 따라 계층적 구조로 분할하고 단계별로 비교분석을 실시하는 階層的 접근(hierarchical approach), (3) 요소들을 속성에 따라 몇 개의 소그룹으로 나누고 각 그룹에 대해 순차적으로 대안들을 비교분석함으로써 고려대상이 되는 대안들을 줄여나가는 順次的 접근(sequtial approach)등을 들 수 있다.

이러한 접근법들의 장·단점들은 사업의 규모나 복잡성에 따라 달라지게 된다. 또한 동일한 접근방법 내에서도 구체적인 기법의 선택과 개발도 문제의 특성에 따라 달리 결정되어야 한다. 그러나 어떠한 경우에도 오늘날의 첨단생산기술에의 투자는 현금의 흐름에 대한 계량적 분석에만 의존하는 전통적인 기법만으로는 불충분하며 기업목표와 생산조직 전반에 관한 전략적 요소들을 포함하는 종합적인 접근이 바람직하다.