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A ROLE FOR COMPUTER SIMULATION IN THE ECONOMIC ANALYSIS OF MANUFACTURING SYSTEMS

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This paper discusses traditional economic analysis methodologies used in evaluating manufacturing systems and points out some potential problems with these methodologies because of the omission of certain cost elements in the analysis and/or not having an appropriate mechanism for accurately estimating certain additional cost elements and product revenues. Integrating computer simulation into the economic analysis methodologies is proposed as a way of eliminating the shortcomings preceived in them. The paper further discusses how computer simulation models can be used to develop product revenues and certain system cost components that are either not included or not estimated accurately in the current approaches.

1. INTRODUCTION

Productivity of manufacturing organizations in the USA has become a very central issue. In the 1970's the average annual growth in productivity in the USA was less than 1%. In 1979, an actual decline was recorded. Management of manufacturing organizations in this country has recognized the seriousness of this problem for some years now and has taken steps to modernize manufacturing facilities. There has never been a conscious effort to do so much so fast. Management of manufacturing organizations is constantly looking at replacing aging facilities with new, more productive ones. At the same time, it is facing two unique problems in its effort to modernize. First, the availability of capital has been limited. Second, due to limited capital availability, only part of the total facilities can be modernized. Thus, it is vital that new facilities successfully interface with the existing ones. Due to these situations it is important for management to very carefully analyze all alternatives available and to evaluate the long term economic implications of each alternative. Modern manufacturing facilities are capital intensive and the impact of economically unsound decisions can be disastrous. Criteria for a generalized methodology for assessing economic consequences of different alternatives have been outlined (Fleischer 1982). Although the outline is developed in the context of acquiring robots, it may be applied to any manufacturing system provided appropriate models are utilized.

The commonly used economic analysis approaches for analyzing various alternatives of modernizing manufacturing systems determine product revenues, capital expenses and other costs involved in each alternative and use an economic model to evaluate these alternatives.

The authors feel that while it is easy to get accurate estimates of capital expenditures and some of the cost components involved in such an analysis, obtaining meaningful data on product revenues and a category of cost components directly related to operating strategies remains a significant problem.

This paper proposes an approach to the economic analysis of manufacturing systems in which computer simulation plays a key role in obtaining estimates of product revenues and certain cost components. A presentation of manufacturing system definition and traditional economic analysis methodologies precede the discussion on the proposed approach.

2. MANUFACTURING SYSTEM DEFINITION

The term manufacturing system refers to a system that receives items and adds value by physically transforming them. Manufacturing systems can be diverse in nature, each having very pronounced idiosyncrasies but they may be generally classified as follows:

1. Process Systems
2. Assembly Systems
3. Batch Manufacturing

Steel and aluminum industries are typical examples of process systems. Automobile industry qualifies as an assembly system. Finally, manufacturing of parts that go into an assembly system can be regarded as batch manufacturing.

The extent to which a manufacturing system is to be designed or redesigned can be determined by defining the functions involved in the new design alternatives. If only one machining center is involved, only its function is evaluated. However, if an entire manufacturing system is being designed, the evaluation will probably include several functions such as:

- Storage (all types)
- Material handling
- Fabrication
- Machining
- Assembly
- Quality control
- Packaging
- Etc.

The idea of manufacturing system components and their interactions becomes involved in the design, thus making the alternative designs larger in number and the evaluation procedure more complex. Figure 1 is a block diagram of a manufacturing system containing several functional components. There are, most likely, several alternative ways to design the overall system by selecting different components and configuring them in one or more ways. For example, machining may be accomplished by a variety of numerically controlled machines with or without robots providing interface with the material handling system, or by conventional machining equipments.

3. TRADITIONAL APPROACHES TO THE ECONOMIC ANALYSIS OF MANUFACTURING SYSTEMS.

The extensiveness of the classical analysis is guided by (1) the degree of complication of the manufacturing system being evaluated and (2) the desired completeness of the cost estimation process. If only a limited number of components are involved in the design and evaluation process, the estimation of costs and revenues will be simpler than if an entire system is being designed. Similarly, if cost estimation is to be comprehensive and includes cost components which are difficult to collect or estimate, the analysis becomes cumbersome.

Commonly, the evaluation model is either a revenue/cost or a cost only relationship (with equal revenues assumed) for a specified planning horizon. The net present value (NPV) at some stated or assumed rate of return is to be computed for each alternative and those with favorable NPV values are used as candidates (Blank & Tarquin 1983). The most favorable, that is minimum NPV of costs or maximum NPV of revenue over costs, is the best candidate design. However, intangible factors often alter the final decision. These may be risk, technology assessment, future product mix plans, etc.

Alternatively, the NPV model may be developed without the required return included and the estimated rate of return on investment (ROI) computed for each alternative. There are some cautions to be observed with this approach. due to mathematical considerations (Bussey 1978 and de la Mare 1982b), but the ROI approach is a viable and commonly used criterion for alternative selection.

When the classical economic model for NPV or ROI analysis is developed, three main cost categories are usually defined. These are :

Equipment costs - Those associated with the initial cost and salvage value of equipments, spare parts, installation, major reworks, etc.

Labor costs - The direct labor and overhead costs of operating and maintaining the equipment.

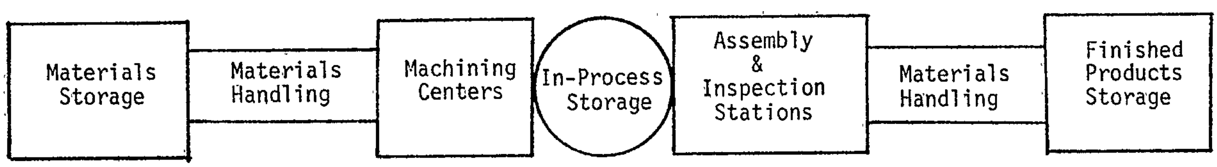

Figure 1: Block diagram of the functional components in a simple manufacturing system.

Product costs - The raw material and scrap costs associated with the product itself.

Figure 2 presents a schematic of the traditional economic analysis approach. If simple revenue/cost modeling is assumed, a typical before-tax NPV model for alternative j (j = 1, 2, ..., n) might appear as follows:

$$NPV_j(T) = -P_j(0) + F_j(T).\frac{1}{(1+i)^T} \qquad (1)$$

$$\sum_{t=1}^{T} [R_j(t) - A_j(t)].\frac{1}{(1+i)^t}$$

where t = year of the planning horizon on the evaluation period for the project (t = 1, 2, ..., T).

$P_j(0)$ = present worth of all equipment acquisition, development and implementation costs at the start-up time, t = 0.

$F_j(T)$ = estimated future worth of the salvageable equipment at the termination of the evaluation period, t = T.

$\frac{1}{(1+i)^t}$ = present worth factor for an annual return of i. If continuous compounding is assumed e^{it} is substituted here.

$R_j(t)$ = estimated annual revenue for all products in year t, commonly modeled as $v_j(t)s$, that is, volume in year t times the average sales price.

$A_j(t)$ = amount which represents the yearly cash outflow to operate, maintain and support a design alternative j. This consists of costs in the labor and product cost categories.

The $P_j(0)$ term represents costs over the entire project planning and implementation period. Besides the manufacturing equipment itself, software acquisition and development as well as systems planning costs are commonly included here. These costs are likely to be incurred over several years and may vary between alternatives. In such a case:

$$P_j(0) = \sum_{t=-s}^{f} p_j(t).\frac{1}{(1+i)^t}$$

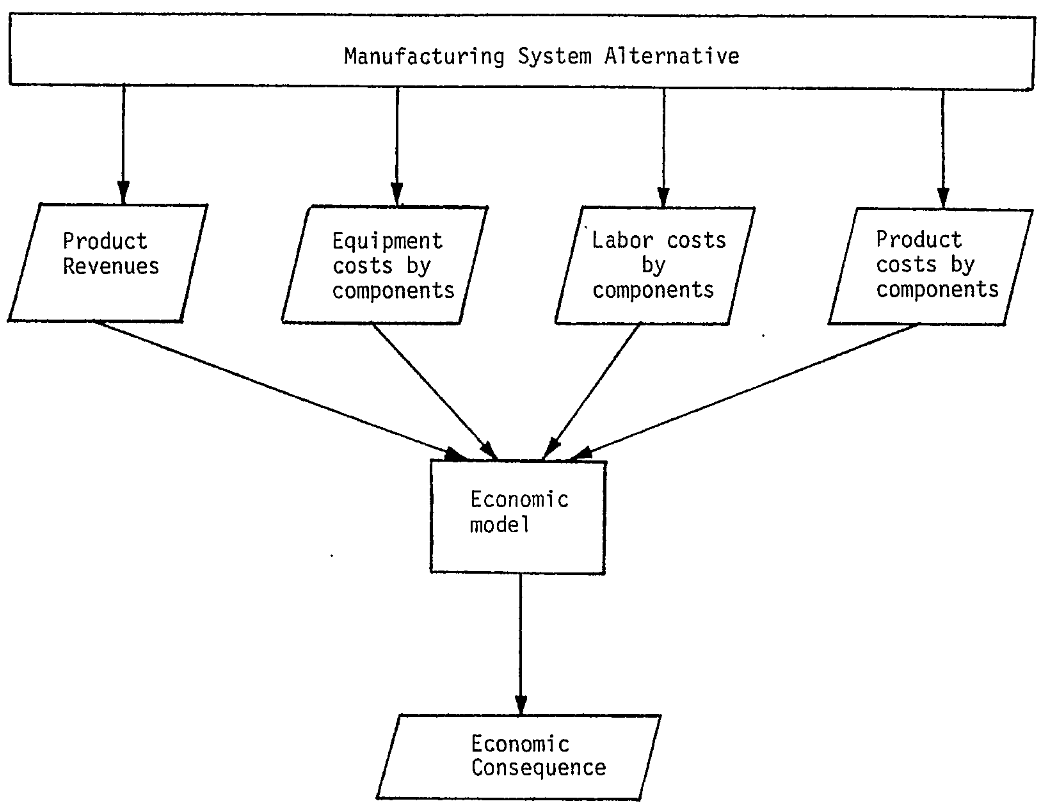

Figure 2: Schematic of traditional economic analysis methodologies

where t = years in the planning and development period of the system $(t=-s,\ldots,0,\ldots,f)$.

$p_j(t)$ = individual component costs for alternative j incurred during the development period.

The cash flows sequences $R_j(t)$ and $A_j(t)$ represent the anticipated annual revenue generated and costs incurred by the manufacturing system. The ability to estimate the $A_j(t)$ value varies depending upon what is included in its definition. Besides the operation and labor costs described above, some models have been developed and implemented to include the effect of additional cost items on the analysis (de la Mare 1975a and Hutchinson & Holland 1982). Some of these are:

- Capacity conversion
- Sales volume charges
- Overcapacity production requirements
- Software maintenance and support
- Safety requirements
- Training

The model in equation (1) is more appropriate when a component oriented viewpoint is not used to define a system. However, when a manufacturing system is viewed as consisting of several functional components such as machining centers, automatic storage and retrieval system (ASRS), material handling system, etc., as illustrated in Figure 1, equation (1) may be written as:

$$\sum_{k=1}^{N} NPV_{jk}(T) = \sum_{k=1}^{N} [-P_{jk}(0) + F_{jk}(T).\frac{1}{(1+i)^T} + -\sum_{t=1}^{T} A_{jk}(t).\frac{1}{(1+i)^t}] + \sum_{t=1}^{T} R_j(t).\frac{1}{(1+i)^t} \qquad (2)$$

where k (1,2,...,N) represents the component and its contents. This allows an analysis of several alternative designs to be done in a differential fashion by eliminating costs of components which may have the same design elements and equipments. $R_j(t)$ is used in lieu of $R_{jk}(t)$ to recognize the fact that total output from the system, not each component k, generates revenues.

If the ROI method is used in lieu of NPV, equation (1) or (2) are still constructed but the rate i^* is found (using a computerized package) such that NPV is zero. If $i^*>0$, its value is compared to an established required return to determine if the alternative is acceptable. This method must be performed on an incremental basis between each alternative (Blank & Tarquin 1983 and Bussey 1978).

4. PERCEIVED PROBLEMS IN TRADITIONAL ECONOMIC ANALYSIS METHODOLOGIES FOR MANUFACTURING SYSTEMS

It needs to be recognized that there are some basic differences between the way economic analysis is performed for a system which consists of one component and the approach that should be taken in economically analyzing a system that consists of a number of components. Unfortunately even the traditional economic analysis approaches, which recognize the component viewpoint, tend to view a system as merely the sum of individual components. In these approaches cost and revenue information (where applicable) about each component are gathered and used in the economic models discussed in the previous section.

A fundamental problem with using the traditional approach to economic analysis is that manufacturing systems cannot be viewed simply as an accumulation of a number of components. In order to characterize a system properly, the interactions of system components must be known. This extra dimension will have an impact on the economic evaluation of a system. The nature of interaction between components is different in each alternative being analyzed. Therefore, the impact due to component interactions on the economic analysis should not be ignored.

The effects of system component interactions can be handled in the economic analysis by including a new cost category in the analysis and ensuring that revenues generated by the system are always considered in the models. This cost category will be referred to as 'operational costs', which depends primarily on the nature of interactions between system components and include portions of $A_j(t)$ and $A_{jk}(t)$ used in equations (1) and (2) respectively that are dependent on component interactions, and some other cost elements. In the traditional approaches some elements of operational costs have been included but no mechanism exists in these approaches to accurately estimate these elements.

Some of the component interaction dependent parameters on which the operational costs are based are:

i) Equipment utilization

ii) Raw material inventory

iii) In-process inventory

iv) Finished products inventory

v) Regular and overtime requirements

vi) System throughput

Operational costs can vary significantly from one alternative to the next and influence the economic consequence of an alternative. For example, component interactions in one alternative may provide a configuration that allows jobs to be scheduled optimally resulting in low in-process inventory and high equipment utilization while the component interactions in another alternative may allow sub-optimal scheduling at best. It should be noted that traditional economic analysis techniques are insensitive to such considerations. Figure 3 shows an example of two alternatives which have the same components, namely, four machining centers, an inspection station, a material handling

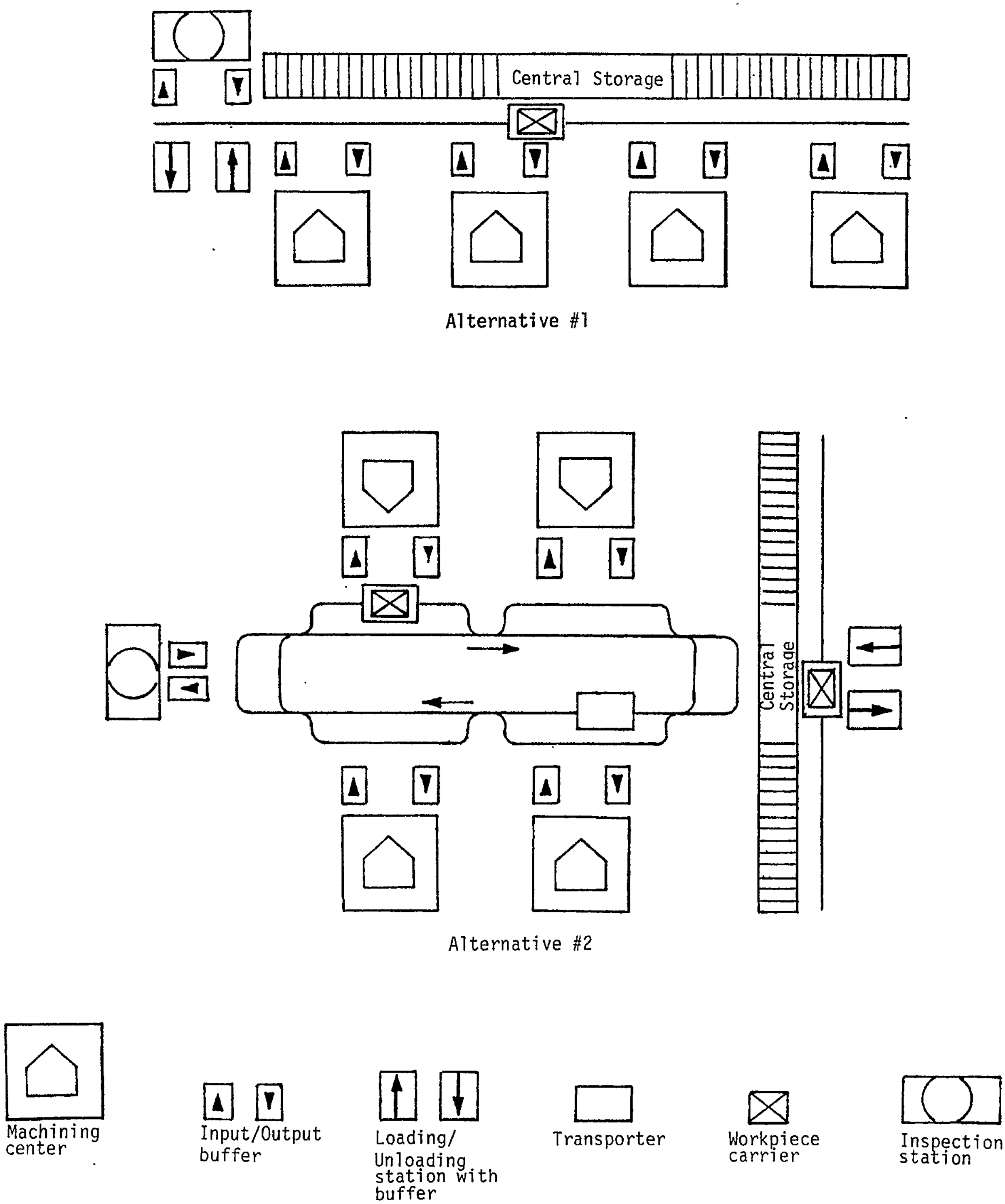

Figure 3: Two alternatives of a basic automated manufacturing system.

system, and an automated storage and retreival system. However, the nature of interactions between the components could be different indicating that the operational costs as well as product revenues may not be the same for the two alternatives. Traditional economic analysis approaches fail to take these aspects into consideration, therefore, they are unable to accurately assess the economic consequences of the two alternatives.

It should be noted that operational costs are incurred in every time period. Therefore, their impact over the horizon of the analysis may be significant even though the operational costs in a specific time period are not large. Similarly, the total throughput from two alternatives of manufacturing systems over the horizon of the analysis could be quite different even if the design capacities of the two alternatives are indicated to be the same. Thus, there is a need for carefully estimating product revenues generated by an alternative. Unfortunately, traditional economic analysis approaches use the design capacities of the system to compute product revenues.

5. ESTIMATION OF OPERATING COSTS AND PRODUCT REVENUES USING COMPUTER SIMULATION

Simulation is widely used to assist in the selection/planning of manufacturing systems (Warnecke & Vettin 1982). It is suggested that computer simulation is an appropriate way to accurately estimate product revenues and operational costs to be used in the economic analysis of manufacturing systems. Revenues and appropriate costs can be determined from system performances as follows:

i) Equipment utilization - Simulation can give good estimates of the utilization of each component in the system. This parameter is necessary to get an accurate estimate of the power usage by the components.

ii) Raw materials inventory - The amount of raw materials inventory required by the system for it to function smoothly can be determined accurately by a simulation model. This amount can be converted into the holding cost to be included in the economic analysis of the alternative being considered.

iii) In-process inventory - Value is added to a product as it goes through each operation. To accurately determine the total in-process inventory cost, the value of the product after each operation and the length of storage at each stage should be known. The total in-process inventory holding cost of one unit of a product can be computed as follows:

$$H = \sum_{j=2}^{m} r \cdot V_j \cdot W_j$$

where

H = total in-process holding cost for one unit of a product.

r = fraction of the value of a product used as the unit holding cost.

V_j = product value before operation j.

W_j = waiting time of a product between operations (j-1) and j.

m = total number of operations required by a product.

Parameters W_j and V_j can be generated by a simulation model of the system.

iv) Finished products inventory - Based on the shipping policy implemented for the system, a computer simulation model will provide good estimates of the finished products inventory. By knowing the value of the finished products, total inventory holding cost of finished products can be calculated.

v) Regular time and overtime labor requirements - By knowing the labor rate on each system component and the utilization of the components, accurate estimates of regular time as well as overtime labor requirements can be made by a simulation model. This information is necessary to compute a portion of total direct labor costs.

vi) System throughput - Certain traditional economic analysis models assume equal revenues for all alternatives being investigated and only include costs in the analysis. Economic models that include product revenues attempt to estimate the volume of the products by using the capacity information of the components. This approach can be misleading as the product volume cannot be estimated accurately using the component capacities only. The actual throughput of the system is likely to be different from the above estimate because of the constraints imposed by the system component interactions. A simulation model can provide accurate estimates of system throughput by product types which, in turn, can be used to compute revenues and some direct labor and product cost elements needed for the economic analysis.

6. CHARACTERISTIC REQUIREMENTS FOR SIMULATION LANGUAGES TO BE USED IN THE ECONOMIC ANALYSIS

Any simulation language to be used in the economic analysis must have a convenient mechanism to model manufacturing systems. To reduce the time needed to develop and debug a simulation model, a language should have the following characteristics:

- Network orientation of system description with minimum amount of user-written interface required.

- Convenient mechanism to define the components of the system on the network as well as their operating policies.
- Internal mechanism to convert the system performance parameters into operational costs.
- A comprehensive output mechanism to provide all the necessary statistics about the operational costs.

SLAM II, GPSS, SIMAN, and GEMS are a handful among the many simulation languages available today to model manufacturing as well as other systems. None of these languages, with the exception of GEMS, has a built-in mechanism to provide statistics on the operational costs of the system. Several operational cost elements can be pulled out of some simulation languages by interfacing user-written commands with the model. SLAM II is a good example in this regard. With today's simulation languages, most difficulty is experienced in accurately generating the total in-process inventory holding cost because the value added to each product after each operation must be recorded internally.

7. RECOMMENDATION OF AN ECONOMIC ANALYSIS APPROACH USING COMPUTER SIMULATION

Figure 4 shows the steps involved in economically

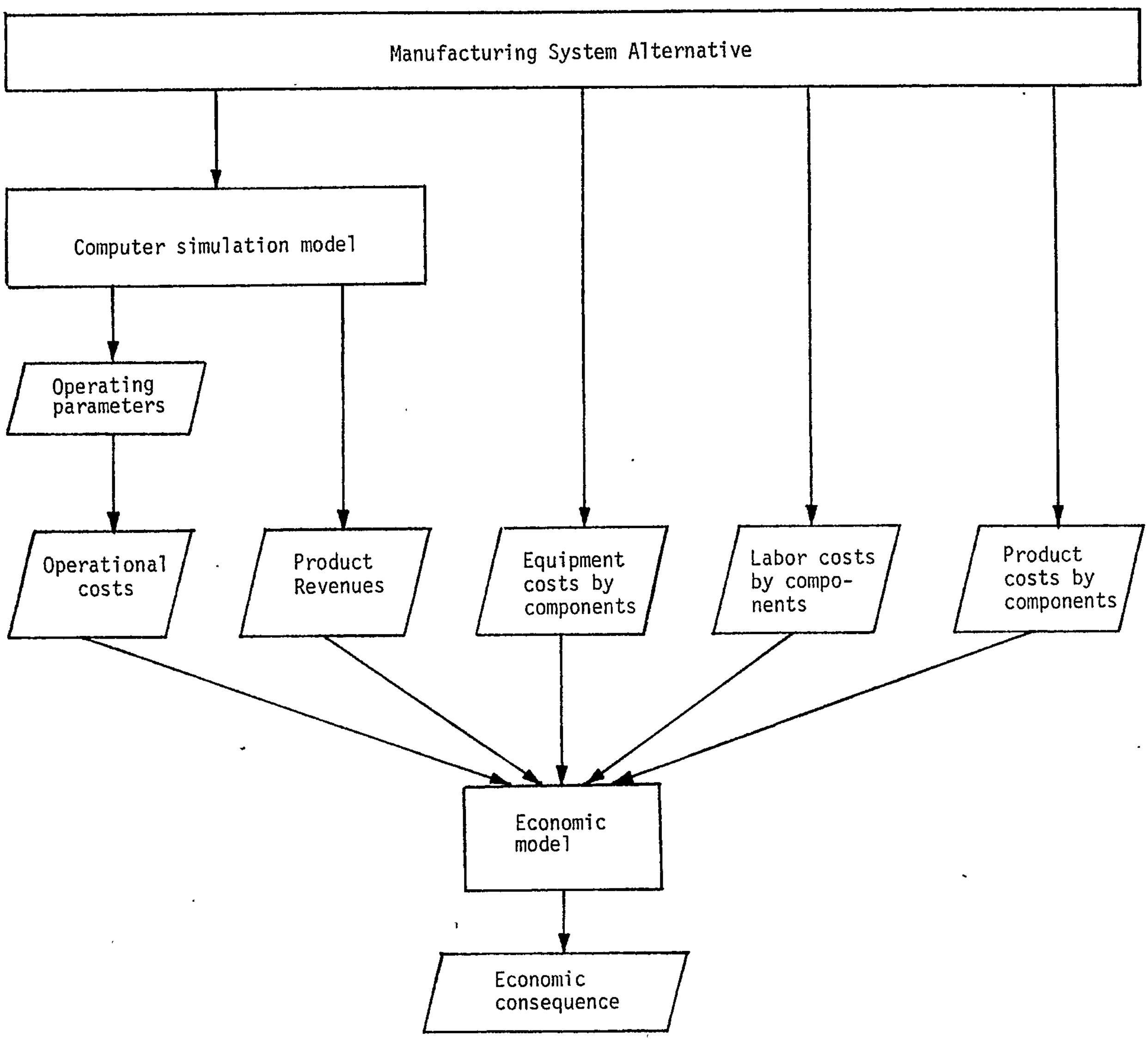

Figure 4: Schematic of the proposed methodology.

evaluating an alternative of a manufacturing system using an integrated approach. In this approach, computer simulation becomes an integral part of the economic analysis of manufacturing systems. This approach evaluates the operational as well as the economic viability of the system at the same time.

All cost estimates, with the exception of operational costs, for a specific alternative are estimated similar to the way they are done in a traditional approach. Along with the development of these costs, a computer simulation model of the alternative is developed and is used to generate product revenues and the operational costs. These values are then input to the economic model in order to determine the consequence of the alternative. An appropriate economic model can be generated by modifying equations (1) and (2). For example, equation (1) can be modified as follows:

$$NPV_j(T) = -P_j(0) + F_j(T).\frac{1}{(1+i)^T} + \sum_{t=1}^{T} [R_j(t)-A_j(t)-O_j(t)].\frac{1}{(1+i)^t}$$

where $O_j(t)$ is the operational costs of alternative j in period t. This model is utilized for analyzing the economic consequence of each alternative. The alternative with the most favorable economic consequence is selected.

It should be noted that a cost only economic model is not appropriate for evaluating manufacturing system alternatives as revenue generation cannot be assumed to be the same for all alternatives due to different system throughputs in the alternatives.

8. CONCLUSIONS

The objective of this paper is to bring to attention a possible problem that may exist in the economic evaluation of manufacturing system alternatives if the product revenues and cost components, categorized as operational costs, are not determined accurately and included explicitly in the analysis.

The role of digital simulation in the design of manufacturing systems has been well established in the literature. It is being proposed here that this widely used technique be used as an integral part of the economic analysis of manufacturing systems as well. In the traditional approach the economic analysis is used to select a manufacturing system alternative and, subsequently, the operational feasibility of the system is established by analyzing different layout/operating strategy combinations of the system components. Therefore the proposed approach is not likely to add significantly to the amount of time required by the existing approaches for the economic and operations analysis of manufacturing systems.

It is necessary to either select or develop a simulation language which allows models of manufacturing systems to be developed and debugged conveniently and rapidly. The simulation language should also have a built-in mechanism to generate product revenues and to collect operational cost elements in the system. Selection of an unsuitable simulation language can make this entire approach very cumbersome and impractical.

At this time it is not possible for the authors to provide any estimate of how significant, with respect to the total cost, are the operational costs. Research is being initiated to investigate this question. However, as pointed earlier, it should be kept in mind that operational costs are not one time costs and, over a long time horizon, they can become quite significant.

Installations of new manufacturing systems or major modifications or expansions of existing systems are very capital intensive and it is critical that the alternative selected be both operationally and economically most cost effective. Efforts should be made to ensure, as much as possible, that all relevant costs have been taken into account as accurately as possible. The impact of choosing a wrong alternative can have a far reaching impact on the manufacturing organization involved.

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