Activity-Based Costing Approach to Equipment Selection Problem For Flexible Manufacturing Systems

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Abstract

The equipment selection problem is essential in manufacturing today. It typically involves the selection of a set of equipment to be used in production based on technical and economical criteria. This paper will focus on an activity-based costing approach to the equipment selection problem for flexible manufacturing systems. The technique developed in this paper will help decision-makers select the appropriate set of equipment or machines to be used in the system based on the objective to minimize total operating cost subject to the availability of machines in the system.

Keywords: equipment selection, flexible manufacturing, activity-based costing

1. Introduction

The assumptions of linear cost functions are popular and continue to be used over many applications (Li and Tirupati, 1992). Furthermore, the costs associated with the products can be classified into two categories (Lewis, 1993):

(1) direct cost is directly traceable to the product itself such as direct labor and direct material
(2) Indirect cost is indirectly related to the product such as machine utilization cost, material handling cost, tooling cost, and so forth.

This study also assumes that the assignment of indirect costs is based on the activity-based costing (ABC) concept since the purpose of activity-based costing is to fairly allocate the indirect costs. “ABC systems are designed to be complementary with the technological changes in the factories due to enhanced global competition” (Lewis, 1993).

Before the equipment selection process can begins, the following data must be obtained:

- Operations or tasks required for each part type
- Candidate machine that are capable of performing each task

- Available time and machining time to perform an operation of each machine
- Fixed cost and operating cost of performing an operation of each machine
- Set up and tooling time and cost of each machine.

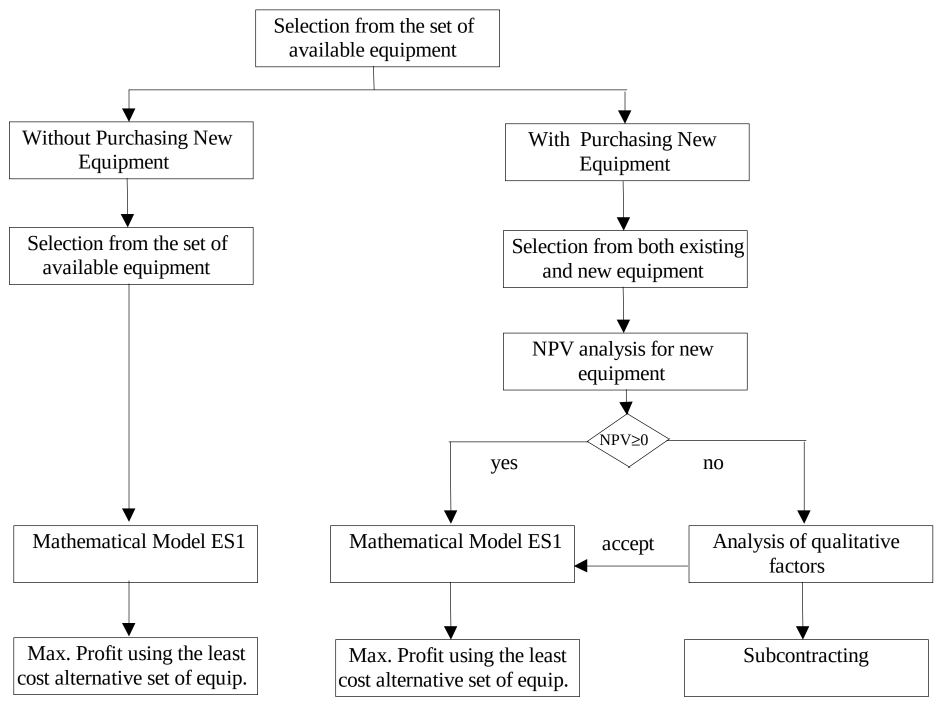

Figure 1 Equipment Selection for Flexible Production Systems

The equipment selection step involves selecting the types and quantity of equipment required to perform a variety of operations. Economic criteria are used in the evaluation of the equipment selection process. The goal of this step is to determine a list of equipment to be used in order to minimize the total cost (equipment depreciation, installation cost, set up cost and operating cost). This problem can be formulated as a linear programming problem.

2. Proposed Equipment Selection Models

This research divided the equipment selection model into two categories:

(1) Equipment selection model with no expansion into new products- this model involves the selection of the most economically set of machines or equipment from what is available. This model can be applied upon the completion of the part selection process. The part selection process is responsible for selecting the part types and amount of each type to be produced without violating the economic and technical constraints.

(2) Equipment selection model with expansion into new products- this model can be used when it is necessary for a company to produce a new product or to expand into an area not currently serving. This model involves the selection of the most economically advantageous set of machines or equipment from what the company has available as well as from what the company does not have.

3. Data Requirements and Model Assumptions

Additional assumptions must be met in order to formulate the equipment selection model are as follows:

- The type of parts and amount of each type to be produced are known.
- The sequence of operations for each part type is known.
- Raw material required to produce parts can be procured before production.
- Processing cost and time for each operation at eligible machines are assumed known.
- List of available and eligible machines from different classes that can perform each operations is provided.
- Tool constraints will not be considered.
- Machine time available (T_m) for all machines in the same class are the same.

3.1 Equipment Selection Model ES1 (No Expansion in to New Products)

3.1.1 Model Formulation for ES1

The purpose of the proposed model is to minimize the total cost of production as stated by the following objective:

$$\text{Min. } [\sum_{m=1}^{M} \sum_{o=1}^{O} X_{om} C_{om} + \sum_{m=1}^{M} \sum_{o=1}^{O} S_{om}\beta_{om} + \sum_{m=1}^{M} (t_{om}/T_m)\beta_m C_m + \sum_{m=1}^{M} \beta_{msta} C_{mst} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{Min. } \sum_{m=1}^{M} [\sum_{o=1}^{O} X_{om} C_{om} + \sum_{o=1}^{O} S_{om}\beta_{om} + (t_{om}/T_m)\beta_m C_m + \beta_{msta} C_{msta}]$$

Constraints:

$$\sum_{m=1}^{M} X_{om} \leq R_o \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$\sum_{o=1}^{O} t_{om} X_{om} + \sum_{o=1}^{O} S_{om} \beta_{om} \leq EF_m \ T \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$X_{om} \geq 0 \quad \text{integer}, \quad o=1,2,\ldots\ldots,O \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$
$$m=1,2,\ldots\ldots,M$$

where,

m	represents index for machine m=1,2,....,M
o	represents index for operation o=1,2,.....,O
X_{om}	represents number of operations 'o' to be performed at machine 'm'
C_m	represents cost of machine 'm'
C_{om}	represents cost of performing operation or task 'o' on machine 'm'
C_{msta}	represents cost for installing machine 'm'
R_o	represents required production rate of task 'o'
T_m	represents time available on machine 'm'
t_{om}	represents time required to perform ask'o'on machine 'm'
S_{om}	represents set up cost (tool changes) for task 'o' on machine 'm'
T	represents total time available
$frac_o$	represents fraction of task 'o' of total production
β_m	represents binary variable equal '1' if machine type 'm' is selected, and equal zero otherwise
β_{om}	represents binary variable equal '1' if operation P(P>O) required tool changes and/or set up, equal zero otherwise

β_{msta} represents binary variable equal '0' if machine 'm' was chosen at period 't-1' or machine 'm'can not be moved and equal '1' if machine 'm' is not chosen at period 't-1'

Total production cost consists of :

(1) Operating costs ($\sum_{m=1}^{M} \sum_{o=1}^{O} X_{om} C_{om}$) derived from the product of operating cost of performing operation 'o' at machine type 'm' and production rate of operation 'o' at machine type 'm'

(2) Set up costs ($\sum_{m=1}^{M} \sum_{o=1}^{O} S_{om}\beta_{om}$) of machine 'm' occur when machine type 'm' needs retooling and reloading in order to perform a new operation 'o'

(3) Fix cost or equipment cost ($\sum_{m=1}^{M}$ (t_{om} / T_m) β_m C_m)) is calculated based on the usage rate of each machine. For example, if equipment type 'm' with a life expectancy of 'T_m' hour is used to perform operation 'o' for 't_{om}' hour, the fix cost will equal to $(t_{om} / T_m)(C_m)$, where C_m is the cost of equipment type 'm'

(4) Equipment installation cost or cost of moving and installing equipment into the system ($\sum_{m=1}^{M}$ $\beta_{msta} C_{msta}$)

Equation 1 minimizes the total production cost (consisting of equipment cost, set up cost, installation cost and operating cost). The first constraint , equation 2, implies that production rate of operation or task 'o' at all machines should not exceed the required production rate of task 'o' (R_o). Second constraint, equation 3, ensures that the operating time and set up time of machines should not exceed the total machine time. An efficiency factor, $EF_{m,}$ for each machine 'm' is introduced so that machine utilization can be reduced hence a dynamic system behavior and machine breakdowns can be anticipated.

3.1.2 Proposed Algorithm for Model ES1

Algorithm is now developed to find suboptimal solution for equipment selection model formulated from the previous section.

Step 1: List all part types p = 1,......,P and quantity of each part type (Q_p = 1,....., N) to be produced in the system (these information can be obtained from the parts selection process).

Step 2: Identify the operations required to produced each part .

Step 3: Identify the eligible machines to perform each operation.

Step 4: Identify the time required to perform operation 'o' at machine 'm' (t_{om}).

Step 5: Identify cost of performing operation 'o' at machine 'm' (C_{om}), set up cost of machine 'm' for operation 'o' (S_{om}), and installation cost of equipment (C_{msta}).

Step 6: Identify the appreciation cost for each equipment used. Fix cost or equipment depreciation cost ($\sum_{m=1}^{M}$ (t_{om} / T_m) β_m C_m)) is calculated based on the usage rate of each machine. For example, if equipment type 'm' with a life expectancy of 'T_m' hour is used to perform operation 'o' for 't_{om}' hour, the fix cost will equal to $(t_{om} / T_m)(C_m)$, where C_m is the cost of equipment type 'm'

Step 7: Identify the routing R_i for i=1,2,....., N for each part type. The routing cost for the production of all parts to be produced in the system must be evaluated. Stecke and Kim (1988) suggested that it may be advantages to operate on a continuous basis, i.e., as soon as any part type in the batch is complete, the new part type can start in its place (Stecke and Kim 1988). Consequently, any required tools for new part type can be loaded at this time

Step 8: Compute the routing cost of all possible alternatives using equation 1-4. The cost components consist of operation cost ($\sum_{m=1}^{M} \sum_{o=1}^{O} X_{om} C_{om}$), set up cost ($\sum_{m=1}^{M} \sum_{o=1}^{O} S_{om}\beta_{om}$), equipment depreciation cost ($\sum_{m=1}^{M} (t_{om} / T_m)\, \beta_m C_m$)), and equipment installation cost ($\sum_{m=1}^{M} \beta_{msta} C_{msta}$).

Step 9: Identify the route with the minimum cost and check whether all constraints are satisfied. If one or more constraints are not satisfied, the next best route that satisfy all constraints is selected.

Step 10: Once the least cost alternative routing is obtained, the type of machines required can be determined.

3.2 Equipment Selection Model ES2 (With Expansion in to New Products)

This model is very similar to the previous model. However, an economic analysis of the new machines or equipment must be done to determine which equipment or machines will be economically justified. Those equipment or machines that are economically justified will become candidate machines for further selection. An economic evaluation of machines or equipment can be determined using the net present value equation of Stevens (1993):

$$NPV = (1-\tau) \sum_{t=1}^{T} (G_t - R_t)\,(P/F\ k,t) \quad \ldots\ldots(5)$$

where

NPV	represents the net present value of after-tax cash flows.
k	represents discount rate
G_t	represents the expected income before taxes for year 't'
R_t	represents the minimum revenue requirements for year 't'
τ	represents tax rate

If the analysis of a specific equipment yield a positive NPV, then that piece of equipment will be added to the list of candidate equipment for further selection process. The further equipment selection process can be some similarly to the aforementioned model.

3.2.1 Data Requirements for Model ES2

Before an economic evaluation of the equipment can begin, the following information must be obtained:

- Information regarding to new equipment such as life-span in years can be obtained
- Estimated yearly gross income must be provided
- Minimum yearly revenue requirements can be obtained.

4. Conclusions

The equipment selection procedure can be used to select the set of equipment that can cost-effectively accommodate the production of the selected parts. The equipment selection algorithms were formulated to minimize the total production cost. Two methods to approach the equipment selection problem were presented in this research. Both approaches include activity-based costing.

The first one is the equipment selection with no expansion into new products (ES1). This method involves the selection of equipment from the set of candidate equipment that is available. This method is suitable for the design of flexible production system. The second method to the equipment selection problem is the equipment selection with expansions into new products (ES2). This method involves not only the selection of equipment from what is available, but also the selection of new equipment from vendors. The second method requires economic evaluation of the new equipment. The net present value analysis should be performed for new equipment before the selection of equipment can be completed. Two mathematical models were developed for the equipment selection problem using linear programming. The incorporation of the concepts of activity-based costing in the formulation of these design models allows the planners to get the estimated cost closer to the real cost. In addition, computer programs were developed for both methods to facilitate the planning of larger systems.

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