Impact of ABC Information on Product Mix and Costing Decisions

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Abstract— **Our primary aim in this paper is to develop and demonstrate a mixed integer programming model that utilizes activity-based cost information to determine optimal product mix and product cost in a multi-product manufacturing environment. The model permits interesting insights to be gained into the evaluation of marginal cost of products and marginal worth of resources for decision making involving product mix, product costing and capacity expansion/contraction. It also addresses the issue of how to determine the cost of idle capacity and attribute it to the different products. An example is presented to demonstrate the findings of the model, which we then compare with analogous results from a traditional linear programming-based approach. Extensions to the mixed integer programming model are also provided.**

I. Introduction

INCREASING complexities of manufacturing processes, rising overhead expenses, and a need for better understanding of capacity utilization have led to the emergence of a new costing approach referred to as activity-based costing (ABC) [2], [3], [5], [7]. The main difference between ABC and *traditional costing* is in the allocation of indirect resources to each product in a multi-product manufacturing environment. We will refer principally to absorption costing systems as "traditional." ABC traces the causal relationships between different cost-incurring activities and the final products, and thus attributes the cost of indirect activities to different products. However, in traditional costing allocation is confined to direct manufacturing processes predominantly involving labor and material costs. In this case costs of indirect activities (referred to as "overhead costs") are spread over sources of direct costs as an overhead percentage [3]. As a result, problems are created in situations involving idle capacity because management does not get information regarding attribution of idle capacity cost to different products. This in turn leads to inequitable pricing and possibly incorrect strategic decisions.

In this paper we evaluate the impact of using detailed ABC information in several important engineering and management decisions such as product mix, product costing and capacity utilization. We then compare decisions based on ABC information with decisions arrived at using traditional cost information. The main purpose of this paper is to illustrate how ABC information can influence the application of mathematical programming models for strategic decision making. We have developed a mixed integer programming (MIP) model to determine optimal product mix using ABC information. Also, this model helps in determining the standard costs and marginal costs of different products in a multi-product manufacturing environment. The model developed herein proposes a solution to the age-old problem of when to use the marginal costs and when to use standard costs in decisions such as product mix, product pricing, or capacity expansion. Also, a novel approach is proposed for conducting sensitivity analysis of profit maximization opportunities in product mix problems. Finally, an example is presented to demonstrate the findings of the MIP model, which we then compare with the findings of linear programming based approach using traditional cost information.

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II. Product Mix Problem

One of the classical applications of linear programming is in the product mix problem [10]. In the context of deciding which products to manufacture, the problem is formulated with the objective of determining the maximum profit from the mix of manufactured products, subject to constraints on the different resources. The objective function coefficients for this problem could be obtained by 1) estimating the contribution margin for each product or 2) estimating the absolute profit per unit of each product. The contribution margin approach is applied in two situations—one is in the direct costing system where the fixed overhead costs are not considered in the cost of each unit of the product, and the second is in the short term planning context where the fixed overhead costs are not relevant to the decision. The absolute profit per unit of each product is used for long range planning with absorption costing. In either case, the generic formulation can be represented as follows:

$$\text{Maximize} \quad Z = \sum_{i=1}^{N} z_i x_i \tag{1}$$

$$\text{Subject to} \quad \sum_{i=1}^{N} m_i x_i \leq M \tag{1a}$$

$$\sum_{i=1}^{N} lb_i x_i \leq L \tag{1b}$$

$$\ell_i \leq x_i \leq u_i \qquad i = 1, \cdots\cdots, N. \tag{1c}$$

z_i is the marginal or absolute contribution per unit of product i depending upon whether it is for a short term or a long term planning model.

x_i is the number of units of product i to be produced in a given time horizon.

N is the total number of different products to be considered.

m_i is the material cost per unit of product i.

lb_i is the labor cost per unit of product i.

M is the cash equivalent of maximum material resource available.

L is the cash equivalent of maximum labor resource available

ℓ_i and u_i are the lower and upper bounds, respectively, on the number of units of product i and are determined from forecasts of demand.

It should be noted that for simplicity of representation, we have shown just a single constraint for each labor and material resource. However, in an actual problem, there could be several constraints for different types of labor, processing methods, materials and so on. Applications of the above formulation can be referred to in [10].

The above model has two shortcomings regarding its assumption of product cost that in turn influences the unit profit z_i:

1) It is confused by the dilemma of whether the marginal cost or absolute cost is relevant. In the case of marginal cost, the assumption is that the indirect costs are fixed and unaffected by the decision parameter x_i. In the case of absolute cost, the assumption is that the indirect costs are directly proportioned to each unit of x_i because the indirect costs are a fixed percentage of the direct costs. The decision maker has to make a subjective decision as to which of the above two assumptions would be more appropriate for a particular situation.
2) The model does not permit the incorporation of different cost details that may be available in an ABC environment. Also, it does not accommodate situations wherein unit costs cannot be determined because they depend upon the production level.

Clearly, what is needed is a more versatile model that can incorporate different types of cost information for different decision situations. The model proposed in the following section facilitates use of detailed ABC information and produces better estimates of true (accurate) costs. In this paper we are fully cognizant that an accurate, or true, cost is inextricably linked with the ability of a decision maker to identify worthy improvements of existing operations and to place values on such improvements as they evolve over time.

A. Proposed Approach

With activity-based cost (ABC) information, we have improved knowledge of indirect (overhead) resource consumption by various products. In the proposed approach, there is no need to assume a unit cost of each product before solving for the optimal product mix. Rather, the model tries to incorporate the characteristics of important cost drivers (factors that influence product cost). To reduce the types of nonlinearities in the cost incurring activities, we assume that the consumption of overhead resources is either in periodic steps or involves a one-time occurrence. The step cost functions for resource j may be denoted as C_j. For instance, an accounts payable clerk can reconcile up to ten orders per hour. Even if the production is less than ten orders per hour, the clerk is on duty and the company incurs the same expense. The same can be said of supervisors, data processing equipment, buildings and infrastructure facilities, and so on. However, if the smallest divisible unit of resource j differs with respect to each product i, we denote the cost of each such increment as C_{ji}. For instance, a certain shop floor area can accommodate three machines for a product i_1, and therefore, its smallest step cost would be one third of the total rent/cost for the area. However, with respect to another product i_2, it can accommodate only two machines. In this case, the smallest step cost is half of the total areas rent/cost. Therefore, C_{ji} is the minimum step increment cost if resource j is increased to meet the demand for additional product i. We define O_j to be the limiting constraint for resource j. This constraint could result from direct limitations on certain indirect resources such as existing infrastructure, skilled personnel, or capital intensive equipment. Then we can formulate the maximization MIP problem as follows:

$$\text{Maximize } Z = \sum_{i=1}^{N}\{s_i x_i - (lb_i + m_i)x_i - \sum_{j=1}^{R} C_{ji}\lceil x_i/a_{ji}\rceil\} \tag{2}$$

$$\text{Subject to} \quad \sum_{i=1}^{N} m_i x_i \le M \tag{2a}$$

$$\sum_{i=1}^{N} lb_i x_i \le L \tag{2b}$$

$$\sum_{i=1}^{N} C_{ji}\lceil x_i/a_{ji}\rceil \le O_j \quad j = 1, \cdots, R \tag{2c}$$

$$\ell_i \le x_i \le u_i \quad i = 1, \cdots\cdots, N \tag{2d}$$

where $\lceil x_i/a_{ji}\rceil$ denotes the smallest integer greater than or equal to x_i/a_{ji},

a_{ji} is the upper bound on the units of product i that can be produced from the amount of resource j that costs C_{ji},

s_i is the selling price per unit of product i,

O_j is the limiting constraint for resource j, and

R is the set of all indirect resources.

Other notation used above has been defined earlier.

C_{ji}, a_{ji} and O_j are the key parameters that translate the ABC information into the proposed model. It should be noted that for a resource j with a one-time cost C_j, a_{ji} will have the value u_i. To demonstrate the implication of these parameters, we consider a situation in which a company has a limited total warehouse space available. Among several products being considered for manufacturing, each product has different requirements for its storage, thus requiring exclusive storage areas. However, once the storage area for one particular product is built, it is sufficient to meet the maximum storage demand for that particular product. In this situation, a_{ji} for product i will have the value u_i. The value of C_{ji} will be

TABLE I
PROFIT AND COST INFORMATION FROM TRADITIONAL COST MANAGEMENT SYSTEM [3] (ALL FIGURES INDICATED IN THE TABLE ARE IN $ PER UNIT OF PRODUCT)

	Product A	Product B	Product C	Product D
1. Selling Price	247	288	830	262
2. Material Cost	75	100	350	90
3. Contracted Services	0	20	50	15
4. Direct Labor (DL)	33.46	35.10	84.10	33.38
5. Overhead (OH) @236.1% of DL	78.99	82.87	198.63	78.80
6. Engineering (EG) @13.8% of DL + OH	15.52	16.28	39.02	15.48
7. General Admin. @22.2% of (4 + 5 + 6)	28.41	29.80	71.44	28.34
8. Cost	231.38	284.05	793.19	261.00
9. Profit Before Tax	15.62	3.95	36.81	1.00

the cost of special storage area for product i, and value of O_j will be the cost of total warehouse area available to the company. This type of product-level detailed cost information for an indirect resource such as storage is rarely provided by a traditional costing system, but it is routinely available information in an ABC environment. Also note that $\lceil x_i/a_{ji} \rceil$ can be represented through a transformation variable y_{ji} (see Appendix).

On solving the problem formulated in (2), we obtain the product mix that maximizes profit. Now, the cost of maintaining the optimal production level for each product i which is selected in the optimal mix can be obtained by the following relation:

$$(lb_i + m_i)x_i + \sum_{j=1}^{R} C_{ji} \lceil x_i/a_{ji} \rceil = TC_i \quad \text{for all } i. \quad (3)$$

TC_i is the total production cost for product i. Per unit cost of product i would be given by $c_i = TC_i \div x_i$ for those i for which $x_i \neq 0$.

Cost of idle capacity that can be attributed to product i is given by expression (4).

$$\sum_{j=1}^{R} C_{ji} \{ \lceil x_i/a_{ji} \rceil - (x_i/a_{ji}) \}. \quad (4)$$

R is the set of all indirect resources (notice that if x_i/a_{ji} is integer then $\lceil x_i/a_{ji} \rceil = (x_i/a_{ji})$ implying that there is no idle capacity for resource j attributable to product i). Also it should be noted that values of step costs C_{ji} and upper bounds a_{ji} can be determined through ABC, and these values are not available in absorption-based costing. These are the key parameters in the proposed model which help in applying the ABC information to product mix and product costing decisions.

III. MARGINAL COST AND MARGINAL WORTH

"Marginal cost is the change in total costs which can be caused due to increase or decrease in the output by a specified quantity" [9, p. 135]. Managers often find difficulties in associating marginal cost with a certain time frame because traditional costing systems do not clearly indicate over what period of time or over what additional quantity of product the variable and fixed overhead expenses will remain unchanged. Thus management may be reluctant to use marginal costing information because of the unknown conditions for which marginal costs are valid.

This drawback in the traditional costing procedure can be overcome by using the proposed approach in formulation (2). The proposed approach causes marginal cost to be dependent upon direct costs as well as indirect costs. To find the marginal cost of additional amount Δx_i, TC_i^{new} can be calculated using expression (3) with x_i replaced by $o_i + \Delta x_i$, where o_i is the optimal value of x_i obtained by solving the optimization problem in (2). The marginal cost for product i will be $TC_i^{\text{new}} - TC_i$ and marginal unit cost ΔC_iwill be given by the following expression:

$$\begin{aligned}\Delta c_i &= (TC_i^{\text{new}} - TC_i)/\Delta x_i \\ &= (lb_i + m_i) + (1/\Delta x_i) \sum_{j=1}^{R} C_{ji} \{ \lceil o_i + \Delta x_i)/a_{ji} \rceil \\ &\quad - o_i/a_{ji} \}. \end{aligned} \quad (5)$$

o_i is the optimal value of x_i obtained by solving the optimization problem in (2). The above equation is true for either increment or decrement in x_i. If x_i increases, both Δx_i and $(TC_i^{\text{new}} - TC_i)$ will be positive, and if x_i decreases, both will be negative. The evaluation of marginal cost by the above method assumes that the constraints on the resources are relaxed to accommodate the above change, given that the mix for the rest of the products is unchanged. However, we could also find the cost of changing x_i by Δx_i without the above assumption. In this case we need to resolve the optimization problem in (2), fixing the value of x_i at $(o_i + \Delta x_i)$. The expression (5) for marginal unit cost is then modified as follows:

$$\begin{aligned}\Delta c_i = (lb_i + m_i) + (1/\Delta x_i) \sum_{j=1}^{R} C_{ji} \{ \lceil (o_i + \Delta x_i)/a_{ji} \rceil \\ - o_i/a_{ji} \} + (Z - Z^{\text{new}})/\Delta x_i. \end{aligned} \quad (6)$$

Z^{new} denotes the objective function value when the problem is resolved with an additional constraint $x_i = (o_i + \Delta x_i)$; o_i is the optimal value of x_i obtained by solving the optimization problem formulated in (2).

$(Z - Z^{\text{new}})$ is the penalty factor for manufacturing product i at a level other than the optimum o_i without changing any constraints on resources.

One of the popular applications of linear programming is to find the marginal worth of a resource in the form of a shadow price, and to use sensitivity analysis to determine the effect of changes in the various problem parameters on the optimal solution. However, carrying out sensitivity analysis with traditional cost information implicitly assumes that changes in the production level would not affect fixed overhead costs, and the variable overhead costs vary in direct proportion to the base quantity (direct labor, material or machine hours). Both these assumptions limit the validity of solutions obtained by formulation (1) using traditional cost information. However, the advantage of duality in formulation (1) is lost in proposed formulation (2) because the proposed formulation is restricted with integrality caused by the term $\lceil x_i/a_{ji} \rceil$. Therefore we cannot find the marginal worth for any of the constraining resources using the shadow prices.

However, the marginal worth of a unit resource, as given by the shadow price in the traditional formulation, is probably of little interest to the practitioner who may be more interested in determining how best to invest for expanding or contracting production capacity. In other words, to what extent should he/she increase investment, in which resources, and how will these increases affect profitability? A solution to this problem can be obtained using the discrete value of additional investment that has been committed for this purpose. The problem can be modeled as

$$\text{Maximize } Z = \sum_{i=1}^{N} \left\{ s_i x_i - (lb_i + m_i)x_i - \sum_{j=1}^{R} C_{ji} y_{ji} \right\} \tag{7}$$

Subject to

$$\sum_{i=1}^{N} m_i x_i \le M + i_m \tag{7a}$$

$$\sum_{i=1}^{N} lb_i x_i \le L + i_\ell \tag{7b}$$

$$\sum_{i=1}^{N} C_{ji} y_{ji} \le O_j + i_j \qquad j = 1, \cdots, R \tag{7c}$$

$$y_{ji} \ge x_i/a_{ji} \qquad i = 1, \cdots, N; \quad j = 1, \cdots, R \tag{7d}$$

$$i_m + i_\ell + \sum_{j=1}^{R} i_j = I \tag{7e}$$

$$i_m, i_\ell \ge 0 \tag{7f}$$

$$i_j \ge 0 \qquad j = 1, \cdots\cdots, R \tag{7g}$$

$$\ell_i \le x_i \le u_i \tag{7h}$$

$$y_{ji} \ge 0 \text{ and integer for all } i \text{ and } j \tag{7i}$$

TABLE II
ACTIVITY-BASED COST INFORMATION FOR CMC

Activity	Unit Cost* (in \$)	UBRC# A	B	C	D	Available Resource
1. Contracted Services	3615	×	150	60	236	\$0.482m†
2. Welding	456	5	33	×	11	1.5 m
3. Assembly	183	6	3	×	14	1.0 m
4. Press	6105	×	165	37	130	1.01 m
5. CNC Machine Time	7312	145	542	63	×	0.75 m
6. Press Time	1673	×	52	12	42	0.86 m

UBRC represents upper bound on the capacity of the smallest resource unit with respect to each product type (corresponds to a_{ji} in (2)–(6)).
*Cost of the smallest resource amount for which cost allocation is made.
× implies that this product does not need the particular activity.
† m indicates million.

where i_m, i_ℓ, and i_j denote decision variables for the amount of investments needed in material, labor, and overhead resource j, respectively. I denotes the total additional investment. Other notation is as defined earlier.

Formulation (7) provides information as to which of the overhead resources need what portion of the committed additional investment. Such information is not provided by the traditional costing approach. Formulation with the traditional costing provides information only on the additional investment needed in the *directly* consumed resources, and the indirect resources would invariably need the fixed predetermined percentage of the additional investment required on the volume-based allocation of overhead.

IV. EXAMPLE

Here we examine an example of Costa Manufacturing Company (CMC) adopted from Hicks [3]. The company has four different product lines. CMC had been using direct labor as a base for charging products with indirect manufacturing costs and conversion cost as a base for distributing both engineering and general/administration costs. The information available from the company's traditional cost system is summarized in Table I.

A. Traditional Approach

CMC is interested in determining optimal product mix for a given planning period subject to the following constraints:

Total available material = \$3 million
Total available labor = \$1.1035 million,
Contracted services = \$0.482 million.

Product limits imposed on the number of items produced for each type of product are:

Product	Minimum	Maximum
A	0	15 000
B	0	15 000
C	0	2000
D	0	12 000

The product mix solution to this problem using formulation (1) gives the following solution (within 0.0001) and a maximum profit = \$0.354 million (rounded to the third decimal place).

TABLE III
INFORMATION FOR CMC OBTAINED THROUGH THE TRADITIONAL COSTING FORMULATION AND THE PROPOSED APPROACH

Formulation	Maximum Profit (in $)	Product Mix A	Product Mix B	Product Mix C	Product Mix D	Unit Cost (in $) A	Unit Cost (in $) B	Unit Cost (in $) C	Unit Cost (in $) D	Profit† Increase	Idle Capacity
Traditional	0.354 m	15 000	11 750	2000	0	231.38	284.05	793.19	261	$2354	NA
Proposed	0.255 m	0	11 847	0	11 960	NA	281.80	NA	246.81	$3694	1.8%

† Indicates profit increase due to an additional investment of $60 000
NA denotes "not applicable"
m stands for million

Product A = 15 000 units Product B = 11 750 units
Product C = 2000 units Product D = 0

B. Activity-Based Approach

CMC's management decided to take another look at cost characteristics within variations of the product line using activity-based costing analysis. Also, they identified the limitations (O_j) on each type of resource that had been earlier lumped together as an indirectly consumed resource. The findings are summarized in Table II. CMC now again sets out to determine the optimal product mix subject to the same constraints as in traditional costing along with the additional indirect resource constraints obtained through activity-based study. From the proposed formulation (2), the solution obtained (within 0.0001) is as follows:

Maximum Profit = $0.255 million (rounded to the third decimal place)
Product B= 11 847
Product D= 11 960 Product A and C are 0.

Compared with the results of formulation (1), we find that the optimal product mix obtained through the proposed formulation has approximately 28% lower profit potential (equivalent to $0.099 million). This implies that formulation (1) gave higher profit potential than is realistically attainable. At the optimum production level, unit costs of products B and D using (3) are $281.80 and $246.81, respectively. Unit costs given by the traditional costing were $284.05 and $261, respectively. The cost differences are approximately 1% and 6% for products B and D, respectively.

C. Sensitivity Analysis

A sensitivity analysis was conducted for formulation (1) and the proposed formulation (7). An investment of $60 000 would result in the following profit increases:

	Profit Increase	Profitability Increase
Formulation (1)	$2354	0.6%
Formulation (7)	$3694	1.4%.

Formulation (1) led to the conclusion that the entire $60 000 should be spent on materials whereas formulation (7) suggested a distribution of $60 000 among contracted services, press and press time, and no investment in materials.

The reason for this difference in how to invest $60 000 came from the fact that the traditional costing approach had all indirect costs being shown as a certain percentage of the labor cost. There were no independent constraints for the indirect resources such as welding, press, etc. As there was slack capacity in labor, formulation (1) assumes that there is slack capacity in overhead resources too. Materials were found to be the immediate binding constraint, and the formulation led to the conclusion that the entire $60 000 should be invested in materials.

However, through the proposed approach using ABC information, it was found that available press time was the immediate binding constraint and the number of presses was the second-most binding constraint. (The constraint on press time could also be translated to represent the available time of skilled press operators.) Having met these two constraints, contracted services was the third-most binding constraint. Contracted services was not a binding constraint in the previous formulation because of a different product mix.

We investigated the effect of applying the product mix arrived at by formulation (1) to that of the proposed formulation (2). It was found that the suggested product mix through formulation (1) was infeasible for formulation (2) because of the constraints on press time and CNC machine time. These constraints were nonexistent in formulation (1). It shows that the traditional costing approach may lead to solutions which cannot be realized because of limitations on supporting indirect resources. These limitations may be overlooked when the costs of the indirect resources are lumped into a single overhead cost and spread over products as percentage of direct costs.

D. Idle Capacity

A total of 1.8% of the system capacity, worth $4600, was determined to be idle due to the intrinsic limitation of the overall production system. This was determined using (4). The complete information obtained through the traditional and proposed approaches is summarized in Table III.

V. CONCLUSIONS

The proposed models provide a mathematical programming framework to adopt detailed ABC information and to apply it to several strategic decisions. In this paper we have concluded that the proposed mixed integer programming approach incorporating detailed information on indirect resource consumption produces different numerical results compared to the model using the traditional costing information. Also, we conclude that with ABC information, the cost of idle capacity attributed to different products can be determined. This can provide much greater accuracy in product costing.

In the example discussed we saw that with the traditional costing approach, it is possible to arrive at a product mix which may not be achievable with a given capacity of indirect resources. It is compelling to suggest that adopting such a product mix might escalate overhead costs which were not anticipated during the early stages of product planning and costing. Such situations probably sound familiar to many engineers and managers working in industry.

However, there are two main limitations of the proposed model. First, this model is limited by the accuracy of all cost information. It is not clear what criterion to use for allocating the cost of those activities which are common to several products. Often these are referred to as "facility sustaining" types of costs (e.g., insurance, property taxes, and top management salaries) [4]. Nevertheless, with the growing popularity of activity-based costing, it may not be too long before we have a well developed criterion for allocating facility-level costs to the product-level.

The second limitation is imposed by the computational requirements of integer programming. Applying the proposed models to large problems generated in an actual manufacturing environment may be a tough challenge even for state-of-the-art IP solvers. We have developed a heuristic solution for large MIP problems resulting from the proposed model. For the detailed results regarding the heuristic solution for this problem, refer to Malik [6]. Further research is needed to develop better integer programming solution methodologies for large size problems generated in actual manufacturing systems.

APPENDIX

An equivalent representation of the maximization problem in (2) into a mixed integer program can be made as follows:

$$\text{Maximize } Z = \sum_{i=1}^{N} \left\{ s_i x_i - (lb_i + m_i - \sum_{j=1}^{R} C_{ji} y_{ji} \right\}$$

$$\text{Subject to } \sum_{i=1}^{N} m_i x_i \le M$$

$$\sum_{i=1}^{N} lb_i x_i \le L$$

$$\sum_{i=1}^{N} C_{ji} y_{ji} \le O_j \qquad j = 1, \cdots, R$$

$$y_{ji} \ge x_i / a_{ji} \qquad i = 1, \cdots, N; j = 1, \cdots, R$$

$$\ell_i \le x_i \le u_i \qquad i = 1, \cdots, N$$

$$y_{ji} \ge 0 \text{ and integer } i = 1, \cdots, N;$$

$$j = 1, \cdots, R$$

where y_{ji} represents the transformation variable for $\lceil x_i / a_{ji} \rceil$. Other notation is consistent with that in model (2-2d).

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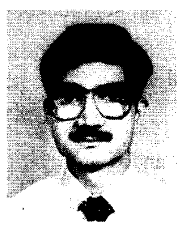

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