Optimization product-mix problem by Implications of Activity-based costing/management

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ABSTRACT

Since determining the optimal product-mix and restrictive bottlenecks is a critical problem. This paper uses the Activity-Based Costing (ABC) approach together with the Theory of Constraints (TOC) for solving this problem. By presenting a new product-mix decision model that uses activity-based with the TOC philosophy, it can be improved the financial performance of a company. A case study is presented based on hypothetical data to show the applicability of the proposed model in different manufacturing systems. The case study shows that the conventional product-mix decision model and the model developed in this paper can give significantly different results regarding the best product-mix and associated bottlenecks of a company.

INTRODUCTION

Determining the optimal product-mix and restrictive bottlenecks is a critical problem to increase the profitability of a company. To make right decisions, management needs more accurate information about the optimal product mix and there restrictive bottlenecks of a company. Activity-based costing (ABC), together with the theory of constraints philosophy (TOC) and mathematical programming, can provide management with more accurate information about the optimal product mix of a company and can help to identify the right bottlenecks that should be focused on to improve the system.

Activity-based costing and management is an accounting and cost management approach which attempts to address the existing deficiencies in the most of the current cost accounting methods. In ABC we first identify the production process activities, and then estimate the cost of each activity individually. These co results in a more accurate estimation of the production process activities, and then estimate the cost of each activity individually. These co activities.

TOC is a management philosophy developed by Goldratt. Based on TOC, the goal of a company is to make money, and there are various constraints that prevent each company from reaching this goal. A constraint is anything that prevents the system from achieving more of its goal. There are many ways that constraints can show up, but a core principle within TOC is that there are not tens or hundreds of constraints. There is at least one and at most a few in any given system.

Various studies have been conducted to demonstrate how linear programming (LP) and TOC philosophy can be used together to determine the best product mix of accompany [1-3]. But researches usually don’t consider any accurate overhead cost allocation that may be crucial in getting the right information. This research shows that using traditional overhead cost allocation approach or ABC may give completely different results about the best product mix and the bottlenecks.

The objective of this research is to combine ABC with mathematical modeling and the TOC approach to improve product mix decisions and performance of a system by using this approach it can provide relevant information to managers that will enable them to make better decisions regarding the product.

Rest of this paper is as follows: literature review section gives a review of the relevant literature. Specifically, it gives information about the principles of activity-based costing and the theory of constraints approaches. Material and method section develops the proposed model that can be used to support the decisions regarding the product mix of a company. Specifically, this section explains how the model is developed based on the current literature. Implication section presents a case study to show how to implement the product-mix

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decision model developed in different situations. Conclusion section includes the conclusions derived from this research and the contribution of this research to the existing body of knowledge.

2. Literature survey:

The main difference between ABC and traditional costing is in the allocation of indirect resources to each product in a multi-product manufacturing environment. 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 [4].

Since the assumptions of ABC are long-term oriented, it can reflect the expected costs of a company correctly in this time frame. Since ABC and TOC are valid in different time horizons, they can complement each other. The weaknesses of one approach can be overcome by the strengths of the other approach, depending on the time horizon [5]. Kee, in his article “Integrating ABC and the Theory of Constraints to Evaluate Outsourcing Decisions” identifies the problems associated with outsourcing and argues that information developed from TOC and ABC may be integrated to evaluate the economic consequences of outsourcing commodity and strategic components. According to Kee, the information obtained from ABC and TOC may be used to evaluate the economic feasibility of outsourcing, the time frame over which it is feasible, and the reasons why it is economically feasible [6].

MacArthur, in his article “Theory of Constraints and Activity-Based Costing: Friends or Foes?” states that ABC and TOC can be considered complementary rather than conflicting or contradictory. According to him, both of these approaches only provide information. Informed management action using that information is necessary to increase the profitability of a company [7].

Campbell et al. argue that ABC and TOC can play complementary roles in the design of a manufacturing information system. In their article, they discuss the development of a customer profitability model based on both ABC and TOC philosophies in a manufacturing company. ABC concepts are applied in those departments of the plant where employees perform supporting and customer service activities. TOC principles are applied to the factory floor, where machine-paced activities are performed. The authors also argue that understanding the principles of both ABC and TOC and applying these principles appropriately can help companies to close the communication gaps between the departments and support cross-functional decision making [8].

Spoede et al. argue that the real potential of ABC is its ability to generate data necessary to support the TOC approach. According to them, the activity-based method does not recognize the importance of an internal constraint in a system, and as a result may give wrong information about the optimal product mix of a company if it is not implemented together with a throughput-oriented management philosophy [9].

MATERIAL AND METHODS

Determining the best product mix that maximizes profits is one of the most fundamental decisions that a company should make. If a company does not have sufficient capacity to satisfy the demand for its products, the best action would be that it should use all of its existing resources and/or expand capacity through capital investment to produce products with the highest profit. The conventional approach to the product mix problem is given below:

Maximize \( \sum_{i=1}^{N} R_i \times X_i \)

subject to

\( \sum_{i=1}^{N} m_i \times X_i \leq MT \)

\( \sum_{i=1}^{N} d_i \times X_i \leq DL \)

\( l_i \leq X_i \leq u_i \)

\( X_i \) is a nonnegative integer variable.

\( X_i \): the number of units of product \( i \) \((Pi)\) that is produced in a specific period

\( N \): the total number of different kinds of products that can be produced in the company

\( m_i \): material cost per unit of product \( i \)

\( d_i \): direct labor cost per unit of product \( i \)

\( MT \): the capital available for material purchase

\( DL \): the direct labor dollars available

\( l_i \): the lower limit of the number of units of product \( i \) that the company must produce during a specific period

\( u_i \): the upper limit of the number of units of product \( i \) that can be produced during a specific period
\( R_i \): the return (profit) per unit of product \( i \)

In the traditional costing approach, the overhead cost is allocated to products based on just one cost driver, generally direct labor dollars. Under this approach, the objective function of the above problem can be calculated as follows:

\[
R_i \times X_i = (s_i - m_i - dli - ovr \times dl_i) \times X_i
\]

\( s_i \): the selling price of one unit of product \( i \)
\( ovr \): the overhead rate is calculated by dividing the total overhead activity capacity by the total direct labor dollars available

Technological improvements and automation has increased the percentage of overhead costs greatly in the new manufacturing environment. Today, direct labor constitutes a very small portion of the total costs incurred in a plant. Consequently, using direct labor dollars as the only basis to allocate overhead costs may give incorrect or misleading information about the profitability of products and may result in poor decisions about the best product mix for a company.

As with any other model, using accurate information in the formulation is the first requirement for a successful product-mix problem. Activity-based costing can give this required information by allocating overhead costs to products based on cost drivers that best represent the consumption of resources by products.

In the proposed approach, three activity levels, the unit-level, the batch-level, and the product-sustaining level, are included in the product-mix decision model by using three different kinds of decision variables described below:

\( X_i \): the number of units of product \( i \) produced in a given time period, \( i = 1, 2, 3, \ldots, N \).
\( Y_i \): the number of batches of product \( i \) produced in a given time period, \( i = 1, 2, 3, \ldots, N \).
\( Z_i = \begin{cases} 
1, & \text{if product } i \text{ is produced in a given time period}, i = 1, 2, 3, \ldots, N. \\
0, & \text{if product } i \text{ is not produced in a given time period}, i = 1, 2, 3, \ldots, N. 
\end{cases} 
\)

\( X_i \) and \( Y_i \) are integer variables, \( Z_i \) is a binary variable.

Facility-sustaining expenses are not included in the analysis because closing the plant is not an option. These expenses do not change with the volume and mix of individual products [10]. The general structures of the three different types of capacity constraints including the three different activity levels are given below. Note that the subscript “\( p \)” is used for unit-level activities, “\( q \)” for batch-level activities, and “\( s \)” for product-sustaining level activities:

\[
\sum_{i=1}^{N} a_{ip} \times cr_p \times X_i \leq PC_p \quad p = 1, 2, \ldots, UL
\]

\[
\sum_{i=1}^{N} a_{iq} \times cr_q \times Y_i \leq PC_q \quad q = UL + 1, UL + 2, \ldots, BL
\]

\[
\sum_{i=1}^{N} a_{is} \times cr_s \times Z_i \leq PC_s \quad s = BL + 1, BL + 2, \ldots, PL
\]

\( a_{ip} \): per unit usage of activity \( p \) by product \( i \)
\( a_{iq} \): per batch usage of activity \( q \) by product \( i \)
\( a_{is} \): per product usage of activity \( s \) by product \( i \)
\( cr_p \): the charge rate of unit-level activity \( p \) performed in a system
\( cr_q \): the charge rate of batch-level activity \( q \) performed in a system
\( cr_s \): the charge rate of product-sustaining level activity \( s \) performed in a system
\( PC_p \): the periodic practical capacity of unit-level activity \( p \) performed in a system (in \( S's \))
\( PC_q \): the periodic practical capacity of batch-level activity \( q \) performed in a system (in \( S's \))
\( PC_s \): the periodic practical capacity of product-sustaining level activity \( s \) performed in a system (in \( S's \))
\( UL \): the total number of unit-level activities performed in a system
\( BL \): the total number of unit-level and batch-level activities performed in a system
\( PL \): the total number of activities performed in a system
The charge rate of each activity \((c_{pr}, c_{r}, c_r)\) is calculated by dividing the budgeted rate of each activity by its practical capacity for a given time horizon. Practical capacity is the maximum capacity of a system adjusted for lost time due to non-working days, plant breakdowns, repairs, and maintenance [11, 12].

In addition to the capacity-related constraints of the overhead activities described above, the following set of constraints must also be included in the new product-mix decision model:

\[
\sum_{i=1}^{N} m_i \times X_i \leq MT \\
\sum_{i=1}^{N} d_i \times X_i \leq DL \\
l_i \leq X_i \leq u_i \quad i = 1,2,\ldots,N
\]

The first two constraints ensure that the amount of raw material and direct labor hours consumed during a specific period do not exceed the available capacities of these two resources in that period. Since the consumption amounts of raw material and direct labor are directly proportional to the number of units of product \(I\) produced during a specific period, \(X_i\) is used as the decision variable in these two constraints rather than the decision variables \(Y_i\) or \(Z_i\). The third constraint guarantees two things:

1. The number of units of product \(I\) produced during a specific period will not exceed the demand for that period.
2. The number of units of product \(i\) produced during a specific period will be at least equal to the lower limit of the number of units of product \(i\) that must be produced during that period.

To define the batch sizes, the following constraint must be included in the model for each product manufactured in the system.

\[
bs_i \times Y_i \geq X_i \quad i = 1,2,\ldots,N
\]

\(bs_i\): the batch size of product \(i\).

This constraint guarantees that whenever one unit of a product \(i\) is manufactured, the relevant batch-level activity costs are incurred in the objective function. If we can assume that a batch of product \(i\) has to be finished completely once that batch is started to be processed, the inequality sign can be replaced with an equality sign in the above constraint. When building the model, we also want to include a constraint that ensures that whenever a batch of product \(i\) is produced, the relevant product-sustaining activity costs are incurred in the objective function. The general structure of this type of constraint is given below:

\[
Y_i \leq M \times Z_i \quad i = 1,2,\ldots,N
\]

\(M\) is a very big number.

This constraint forces \(Z_i\) to be equal to one whenever a batch of product \(i\) is produced in the system.

The objective function of the proposed product-mix decision model is to maximize profit. In the proposed model, profit can be calculated by subtracting the costs of direct labor, material, and overhead activities consumed by each product during a specific time period from the total revenue earned during the same period:

\[
\sum_{i=1}^{N} (s_i - m_i - d_i) \times X_i - \sum_{p=1}^{UL} \sum_{i=1}^{N} ac_{ip} \times c_{r} \times X_i \\
- \sum_{q=UL+1}^{BL+1} \sum_{i=1}^{N} ac_{iq} \times c_{r} \times Y_i - \sum_{s=BL+1}^{N} \sum_{i=1}^{N} ac_{is} \times c_{r} \times Z_i
\]

Implication:

The purpose of this case study is to show how the traditional costing and activity-based costing approaches can give greatly differing results in terms of the best product mix and capacity constraints of a company. To demonstrate this difference between the two approaches, two mathematical models can be used to determine the optimal product mix of a company by using first the traditional costing method and then the activity-based costing based on an evaluation of the data derived from a hypothetical company. The ABC Company has three main products. The current selling price, the monthly demands, the batch sizes, the material cost, and the direct labor cost information for each product are given in Table 1.

**Table 1**: The three main product of the ABC Company

<table>
<thead>
<tr>
<th></th>
<th>Product 1</th>
<th>Product 2</th>
<th>Product 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selling price</td>
<td>34</td>
<td>35</td>
<td>31</td>
</tr>
<tr>
<td>Monthly demands</td>
<td>130000</td>
<td>150000</td>
<td>100000</td>
</tr>
<tr>
<td>Batch size</td>
<td>7000</td>
<td>6500</td>
<td>4000</td>
</tr>
<tr>
<td>Material cost (per unit)</td>
<td>35</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>Direct labor cost (per unit)</td>
<td>3</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 2: The calculation of the charge rates for each overhead activity

<table>
<thead>
<tr>
<th>Activity number</th>
<th>Overhead Activity</th>
<th>Cost Drivers</th>
<th>Budgeted Rate</th>
<th>Monthly Capacities</th>
<th>Practical Charge Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Set up</td>
<td>No. of setup labor hours</td>
<td>260000</td>
<td>500</td>
<td>520</td>
</tr>
<tr>
<td>2</td>
<td>Material Handling</td>
<td>No. of components</td>
<td>60000</td>
<td>350</td>
<td>171.5</td>
</tr>
<tr>
<td>3</td>
<td>Depreciation</td>
<td>No. of inspections</td>
<td>8000</td>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>Maintenance</td>
<td>No. of machine hours</td>
<td>150000</td>
<td>500</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>Packing &amp; Shipping</td>
<td>No. of components</td>
<td>100000</td>
<td>3000</td>
<td>33.3</td>
</tr>
</tbody>
</table>

Table 3: The overhead activity consumption of product 1, product 2, and product 3.

<table>
<thead>
<tr>
<th>Activity number</th>
<th>Overhead Activity</th>
<th>Product 1</th>
<th>Product 2</th>
<th>Product 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Set up</td>
<td>16 setup labor hours</td>
<td>8 setup labor hours</td>
<td>14 setup labor hours</td>
</tr>
<tr>
<td>2</td>
<td>Material Handling</td>
<td>12 components</td>
<td>10 components</td>
<td>10 components</td>
</tr>
<tr>
<td>3</td>
<td>Depreciation</td>
<td>200 inspections</td>
<td>250 inspections</td>
<td>300 inspections</td>
</tr>
<tr>
<td>4</td>
<td>Maintenance</td>
<td>0.3 machine hours</td>
<td>0.2 machine hours</td>
<td>0.3 machine hours</td>
</tr>
<tr>
<td>5</td>
<td>Packing &amp; Shipping</td>
<td>8 components</td>
<td>8 components</td>
<td>10 components</td>
</tr>
</tbody>
</table>

Five major overhead activities are performed in the plant to produce three products. The information regarding the budgeted rate, the practical monthly capacity, the cost driver, and the charge rate of each activity are given in Table 2. The charge rate is calculated by dividing the budgeted rate by the monthly practical capacities. Practical capacity is the maximum capacity of a plant adjusted for lost time due to non-working days, plant breakdowns, repairs, and maintenance. The monthly capacities of direct labor and material consumption activities are $270000 and $5000000, respectively. The demands for these kinds of activities are dependent on the number of batches produced, not on the number of units produced. However, direct labor, material, depreciation, and maintenance are unit-level activities and are dependent on the volume of units produced. The activity usage per unit or per batch of each product is given in Table 3. The information regarding the seven major overhead activities performed in the ABC Company could be obtained mainly from the general ledger and through the interviews conducted in the company.

The objective functions of both models are to maximize profit. Profit is calculated by subtracting the direct labor, material, and manufacturing overhead costs of products from the total revenue in both models. However, there is an important difference in the allocation of total manufacturing overhead costs to the products between the two models.

Both models are solved by using Lingo. According to this model, the most profitable product is P1 and the best action is to spend all of the available resources of the plant to produce 110000 units of P1. The bottleneck in this case is the quality assurance activity because the amount of slack capacity of this activity is equal to zero. Under the traditional costing method, the cost of producing one unit of P1 is $28.3. Since the selling price of P1 is $27, the profit per unit of P1 is $1.78 under the traditional approach. When the per unit cost of P1 is calculated by the ABC approach, it is found to be $27.2. Under ABC, the company appears to be losing $0.93 for each unit of P1 that it produces. This suggests that allocating overhead costs arbitrarily to the products (based on only one cost driver) gives the company incorrect information about the profitability of a product and could lead management to make wrong decisions such as using all the available resources of the company to produce an unprofitable product.

Conclusions:

This paper addresses using direct labor dollars as the only basis to allocate overhead costs that may give misleading information about the profitability of products and may result in poor decisions about the optimal product-mix and bottlenecks of a company. However, using an activity-based cost approach, the best product-mix of a company and developing a new product-mix decision model accordingly is presented in this paper. A case study based on hypothetical data is included in this research to demonstrate the applicability of the proposed product-mix decision model indifferent manufacturing environments. Based on the findings of the case study, it can be concluded that using direct labor dollars as the only basis to allocate overhead costs can give misleading information about the profitability of products and can cause companies to manufacture unprofitable products.

REFERENCES


