Int j simul model 7 (2008) 4, 165-175
ISSN 1726-4529 Short scientific paper

IDENTIFYING POTENTIAL BOTTLENECKS THROUGH ACTIVITY UNDER-UTILIZATION COST

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Abstract
Due to the increased emphasis on technology, modern manufacturing processes are no longer labor intensive. Therefore, the traditional cost estimation approaches based on volumetric measures are inadequate to asses the costs accurately. Contemporary approaches such as activity based costing have been suggested that track hidden costs by relating them to the specific activities, thus providing a much more realistic estimation for manufacturing costs. Since activity based costing does not assign cost of under-utilized resources to customers, the issue of resource under-utilization remains unaddressed. The present paper recognizes resource under-utilization cost to be an important consideration in order to identify the potential bottlenecks in the manufacturing process. This paper proposes an activity based costing model to identify resource under-utilization assuming normally distributed demand. In light of futuristic uncertainty about order sizes and in order to validate the proposed model, a discrete-event simulation approach has been presented.
(Received in November 2007, accepted in August 2008. This paper was with the author 3 months for 3 revisions.)

Key Words: Simulation, Manufacturing Costs, Resource Under-Utilization, ABC Costing

1. INTRODUCTION

Cost inaccuracy may push a company towards an unprofitable venture. An under-estimation of cost leads to financial losses from reduced revenues. On the other hand, an overestimated cost represents a lost opportunity to successfully bid for a profitable product. In either case, it represents a loss for the company. The traditional volumetric approach to cost estimation mainly calculates labor costs based on product volume and then assign a percentage for the overhead costs. However, in modern manufacturing processes, labor cost represents a small fraction of the total corporate costs whereas overhead expenses have increased significantly. Research results indicate that indirect costs have grown from 40 % to 75 % of the entire costs, while direct labor costs have diminished from 55 % to 25 % in many industries [1]. The problem lies in the fact that the traditional cost estimation fails to recognize the individual manufacturing activities which contribute to the cost pool. Furthermore, the traditional approach does not account for factors such as technology, product variety, process complexity, energy and administration. These days, most activities are no longer labor intensive as modern manufacturing processes are becoming more automated and technology-based. Therefore, the use of volume and labor requirements as a basis for computing the manufacturing cost does not truly reflect the modern manufacturing practices. This leads towards erroneous cost estimation resulting from under-estimated costs for low volume complex products and over-estimated costs for high volume simpler products. Limitations of these methods prompted researchers to devise newer ways to allocate costs across several cost drivers. A new costing method called activity-based costing was proposed in [2-5].

According to ABC approach, we need different activities in order to manufacture a product and these activities in turn need the resource capacities which drive the overhead costs. Therefore, ABC tracks hidden overhead costs by relating them to the specific activities that cause them. This micro level approach provides a much more realistic estimation of costs. According to the ABC approach, the entire manufacturing organization is viewed in terms of individual activity cost pools. Under each cost pool, an activity is assigned a cost rate in terms of monetary value per unit of the cost driver. A set of all activities along with their cost rates is known as the bill of activity structure [5]. An important operational benefit of bill of activity structure accrues from the fact that this structure helps to identify activities with high cost rates. These activities should be carefully monitored in order to control the costs. Furthermore, it is possible to conduct a value analysis to identify activities that are cost drivers but adding no value to the final product. These activities are good candidates for pursuing cost reduction through downsizing and lean manufacturing. Classifying the manufacturing process into various cost pools also helps to identify which activities should be deployed to perform operations on products with strategic importance to the company and how this leads to achieve the strategic objectives.

2. PROBLEM BACKGROUND

It has been argued that cost of carrying excess capacity should not be charged to customers [4], mainly due to two reasons. First, the resource underutilization occurs because of a firm’s inability to consolidate different orders resulting in a resource scheduling inefficiency and a customer is not responsible for this resource mismanagement. Secondly, if a customer is made to pay for this excess capacity, it can trigger a vicious cycle that will adversely affect a company's business. The increased costs due to excess capacity resulting in higher prices for customers will lower the product demand. The reduced demand will further result in under-utilization of resources leading towards higher costs, higher prices, lower demands and this vicious cycle continues. A potential exists to manage the resources better by allowing a cost structure where the resources are shared among a group of customers. Examples include, a local tour operator offering package prices based on group sizes, chartered flights, logistic providers charging truck loads rates and consolidating orders for different customers in a single delivery. However, it is still a valid argument that a customer paying for the resource mismanagement of a company will have a negative impact on the business. Following this logical argument, activity based costing does not suggest assigning the cost of under-utilized resources to the customers. Therefore, the cost of resource under-utilization does not get its due attention. The present paper recognizes resource under-utilization cost to be an important consideration in order to identify potential bottlenecks in the manufacturing systems for a better resource management. The present paper provides an activity based costing model to identify resource under-utilization assuming normally distributed demands. The main justification for picking the ABC methodology to identify potential bottlenecks lies in the fact that we need activities in order to manufacture a product. These activities in turn need resources. Therefore, having an activity structure is the ideal way to proceed in order to identify bottleneck resources and ABC methodology provides that activity structure. However, the objective of the present paper differs from the traditional ABC costing approach in the sense that whereas ABC avoids the capacity under-utilization issue, the present paper emphasizes on computing these costs as it can give important insights into potential bottlenecks where investments are needed. These costs provide valuable information on how to realign and re-allocate the resources across activities. The present paper further recognizes that uncertainty prevails due to the random nature of customer orders making it more difficult to asses the under-utilization cost. In a dynamic e-business environment where new orders can be entered, cancelled or modified using internet, uncertainty in order sizes can significantly affect the variation in the cost structure. Since the issue deals with futuristic uncertainty, therefore, one needs to run several what-if scenarios based on different order sizes in order to asses the realistic costs with certain degree of belief. In order to achieve this objective, the current paper presents discrete-event simulation to asses the activity based costs of under-utilized resource capacities under uncertain order sizes. The second objective of the simulation experiment is to validate the cost model proposed in this paper by showing the proximity between the result from the proposed cost model and the results from simulation experimentation.

3. LITERATURE REVIEW

Before presenting the proposed model and the simulation experiment, we review the relevant literature on the problem. Cokins [6] provides a four point criteria for traditional costing method to work i.e. fewer and similar products; low overheads; homogenous nature of the demand, marketing and manufacturing channels; and low selling, distribution and administration. Beginning with the pioneering work on ABC methodology [2-5], a number of other authors have discussed ABC under different scenarios and application areas. Innes & Mitchell [7] analyze the concept of ABC with several case studies. The works of Collins & Werner [8]; Ness & Cucuzza [9] and Bellis-Jones & Develin [10] goes towards explaining the potential benefits that accrue from ABC in strategic costing decisions. Cooper [11] provides guidelines for implementing an activity based costing system. Bruesewitz & Talbott [12] discuss the ABC implementation issues in complex organizations. Gunasekaran et. al [13] shared their experiences of applying ABC across several companies to improve their overall operational effectiveness. Malmi [14] and Maher & Marais [15] highlight the potential drawbacks in using ABC cost methodology. Miquela [16] and Lalonde & Pohlen [17] discuss the usefulness of ABC by applying it in logistics and supply chain management areas. Application of ABC in assessing the product cost in a cellular manufacturing system has been provided by Dhavale [18]. The issue of uncertainty in activity rates in costing has been addressed by Nachtmann & Needy [19] and a simulation analysis encompassing triangular distribution, normal distribution and fuzzy membership functions has been performed. Attempts have also been made to integrate ABC costing with the contemporary approach of theory of constraints [20-21]. A relatively new dimension has been added to ABC costing by Kaplan & Anderson [22] by introducing the concept of time-driven activity based costing. Parallel to the activity based costing methodology, Deo [23] suggests a manufacturing specific approach called operations based costing that relates operations costing and productivity measurement at a micro level structure comprising machines, fixtures, operators, space, contract, incentive, materials and tied capital resources. Deo [23] approach helps engineers and shop floor managers to assess productivity of a shop floor and its usefulness is demonstrated by applying it to mining as well as agricultural automobile industries. The literature on simulation modeling is quite rich. Fairly extensive literature surveys on simulation methodologies are available. Stanford & Graham [24] provides a survey of companies that use low cost simulation software and evaluates how successful they are with these products. A review of discrete event simulation literature before 1987 is available in Kaudel [25]. Swisher et. al [26-27] provides a more recent and fairly extensive survey of simulation techniques published since 1988. For details on Monte-Carlo and discrete event simulation method, the reader is referred to Rubinstein [28], Fishman [29] and Law & Kelton [30]. In the present literature review, we will only discuss the literature on simulation that is relevant to ABC costing. Helberg et. al [31] provides a tutorial introduction to ABC and describes the difference between conventional cost accounting and ABC accounting by means of simulating a production environment. Gardener et. al [32] demonstrates benchmark tests of activity-based costing versus traditional costing in product mix decisions using a simulation model. Takakuwa [33] suggests a framework for simulation modeling in ABC costs in a flexible manufacturing system. Swain & Gladwin [34] consider the example of a mortgage service center to demonstrate how ABC and simulation tools can provide a wealth of information for a complex bank service process. Spedding & Sun [35] use visual interactive simulation software (WITNESS) to model the activity based costing of a semi-automated printed circuit board assembly line. Rasmussen et. al [36] presents an integrated simulation and activity-based management approach for determining the best sequencing scheme for processing a part family through a manufacturing cell. Glick et. al [37] developed a simulation model to measure costs in a hospital emergency department for patients with possible cervical-spine injury who needed radiological imaging. Lee & Kao [38] apply ABC costing in conjunction with simulation techniques to analyze the operational costs of the Pu-Shin wholesale fish market in Taiwan. Drake et. al [39] discusses how organizational control features can affect the use of the information provided by ABC systems and the authors demonstrate it through an active learning simulation involving two student teams that are furnished with identical ABC cost drivers but separate incentive plans. Kataoka et. al [40] combines simulation and ABC analysis to propose a unified approach for process redesign in business process re-engineering. The issue of capacity under-utilization has been discussed by relatively fewer authors. Balanchandran et. al [41] suggests disaggregating unused capacity into different categories to generate decision-relevant information for managing excess capacity. Sopariwala [42] analyzes the fixed capacity costs by looking at the unused capacities, changes in capacity levels and the resource capacities utilized between different years. Zoltan & Viktor [43] emphasizes on the cost of unused capacity and formulate a linear programming model to rationalize the use of unused capacity in a flexible manufacturing environment by taking into account the unused capacities of different machines at different levels. As evident from this literature survey, ABC costing as well as simulation methodologies have been used both independently as well as in conjunction with each other. The present paper differs from the past literature in the sense that it concentrates on a particular issue of cost under-utilization and shows its usefulness to identify process bottlenecks. It also provides a mathematical model and validates it with the general purpose approach of discrete event simulation which is commonly used for validation purposes.

4. MANUFACTURING COST MODEL

The cost model proposed in this section essentially follows the idea of ABC approach by assigning activity rates to different activities, but the purpose is to compute the under-utilization cost.

4.1 Assumptions

The following assumptions have been made in the proposed cost model.

(i) If the total demand exceeds the total capacity, then the orders are truncated in proportion to their order sizes. Likewise, if the total capacity is more than the total demand, then the underutilized capacity is split in proportion to the order sizes.

(ii) The order size information is assumed to have followed a normal distribution.

(iii) Two orders have been considered in the proposed model, but there is no loss of generality as the model is extendable to accommodate more than two orders.

(iv) It is assumed that both orders use the same set of resources with different activity rates. Again, with no loss of generality, if an order requires a slightly different set of resources, the entire resource set can be considered and the activities not requiring certain resources can be assigned zero activity rates.

4.2 Notation

Before developing our cost model, let us state the main notation that has been followed throughout the paper.

$Q_c\ (\mu_c, \sigma_c)$ - Current order with mean of μ_c and standard deviation of σ_c.
$Q_o\ (\mu_o, \sigma_o)$ - The other order with mean of μ_o and standard deviation of σ_o.
$Q_T\ (\mu_T, \sigma_T)$ - Total demand with a mean of μ_T and standard deviation of σ_T.
R_{ci} - Activity rate for activity i for the current order.
R_{oi} - Activity rate for activity i for the other order.
A_i - Activity requirement for activity i by the current order.
C_i - Total allocated pool cost for activity i.
LC - Direct labor cost for the current order.
MC - Direct material cost for the current order.
UC_i - Under-utilization cost for activity i.
TUC - Total under-utilization cost of all activities for the current order.
TOC - Total overhead cost assigned to the customer.
TOC_m - Total overhead cost to the manufacturer.

4.3 The cost model

Since the individual orders follow a normal distribution as per the second assumption, the total demand expressed as the sum of current order and other orders also follows a normal distribution as given below:

$$Q_T\ (\mu_T, \sigma_T) = Q_c\ (\mu_c, \sigma_c) + Q_o\ (\mu_o, \sigma_o) \tag{1}$$

where, $\mu_T = \mu_c + \mu_o$ and $\sigma_T^2 = \sigma_c^2 + \sigma_o^2$.

The resource cost of activity i, RC_i, consumed by current order and the other order is given as follows:

$$RC_i = (A_i \times R_{ci} + A_i \times R_{oi} \times \mu_o / \mu_c) \tag{2}$$

The under-utilization cost (UC_i) for an activity i, which is the difference of allocated cost (C_i) and the cost consumed by both the orders (RC_i), also follows a normal distribution with a variance of $\sigma_u^2 = \sigma_T^2$ and the expected value which can be written using eq. (3) as follows:

$$UC_i = (C_i - A_i \times R_{ci} - A_i \times R_{oi} \times \mu_o / \mu_c) \tag{3}$$

Following assumption (i), the under-utilization cost of activity i, given in eq. (3) can be split in proportion to the order sizes as follows. The under-utilization cost of activity i assigned to the current order, UC_{ci}, is given below in eq. (4):

$$UC_{ci} = (\mu_c / (\mu_o + \mu_c)) \times (C_i - A_i \times R_{ci} - A_i \times R_{oi} \times \mu_o / \mu_c) \tag{4}$$

Total under-utilization cost of all activities in the current order, TUC, is a summation of eq. (4) over all the activities and is given in eq. (5):

$$TUC = \sum_i \left[(\mu_c / (\mu_o + \mu_c)) \times (C_i - A_i \times R_{ci} - A_i \times R_{oi} \times \mu_o / \mu_c)\right] \tag{5}$$

The total overhead cost assigned to the customer, *TOC*, as suggested by ABC costing method, is given in eq. (6) as follows:

$$TOC = \sum_i [A_i \times R_{ci}] \quad (6)$$

The total overhead cost incurred by the manufacturer would be a summation of the costs given in eq. (5) and eq. (6). Adding eq. (5) and (6) and simplifying further, the total overhead cost of the manufacturer represented by TOC_m, is given in eq. (7) as follows:

$$TOC_m = (\mu_c / (\mu_o + \mu_c)) \times [[(\mu_c / \mu_o) \sum_i C_i] + \sum_i A_i \times R_{ci} - \sum_i A_i \times R_{oi}] \quad (7)$$

The cost given by eq. (7) is the total overhead cost for all the product units in the current order quantity, μ_c. The average manufacturing cost per unit can be calculated using eq. (8) as below:

$$\text{Average unit manufacturing cost} = ((TOC_m + LC + MC) / \mu_c) \quad (8)$$

where TOC_m can be obtained from eq. (7).

Eq. (3) and eq. (8) are of particular interest in this model. Eq. (3) can be used to identify the potential bottleneck activities in a manufacturing process as shown in the numerical example. Results from eq. (8) are compared against the results from simulation experiment in order to validate the above model.

5. COST SIMULATION MODEL

Next, we develop a simulation procedure to generate the simulated average unit manufacturing cost and compare it with the cost determined from eq. (8). The purpose of this exercise is to validate the cost model of eq. (8) by comparing it with what-if scenarios generated from the simulation experiment. The simulation model essentially tests the robustness of the model while taking into account any unusual events and likelihood of their occurrence. The procedure has the following steps:

Step1 This step generates the standard normal deviate or Z-score for the normal distribution. The method employed in this step is based on central limit theorem. For n independent variates, X_i with $E(X_i)= \mu$, $var((X_i)= \sigma^2$, $i = 1, 2, \ldots, n$; the standard normal deviate (z-score) given by eq. (9) converges asymptotically to natural number interval N(0,1):

$$Z = \frac{\sum_{i=1}^{n} X_i - n\mu}{n^{1/2}\sigma} \quad (9)$$

If the numbers are generated from a uniform distribution between N(0, 1) i.e. for all $n \in U(0, 1)$, $\mu = ½$ and $\sigma = 1/(12)^{1/2}$, the Z-score transforms to eq. (10) as follows:

$$Z = \frac{\sum_{i=1}^{n} U_i - n/2}{\sqrt{n/12}} \quad (10)$$

We consider an approximation of eq. (10) by considering a convenient value of n = 12. Setting n = 12 in eq. (10), it transforms to eq. (11) which is given as follows:

$$Z = \sum_{i=1}^{12} U_i - 6 \quad (11)$$

Using the excel function RAND( ), we generate 12 uniformly distributed random variates, U_i for i = 1, 2,…12. These random values of U_i act as the seeds for eq. (11) and allow us to calculate the value of standard normal deviate or Z-score using eq. (11).

Step 2 We generate the demand or the size of the current order. Following step 1 and calculating the value of Z-score using eq. (11), we generate current order size, X, as given in eq. (12):

$$X = \mu_c + Z \times \sigma_c \tag{12}$$

Step 3 In step 3, we generate the simulated demand or the size of the second order. Following step 1 and using the value of Z-score from eq. (11), we generate other order amount as eq. (13) below:

$$Y = \mu_o + Z \times \sigma_o \tag{13}$$

Step 4 Making use of cost model presented in eq. (7) and eq. (8) and replacing μ_c and μ_o with simulated values of X and Y respectively, the simulated unit manufacturing cost for the current order is given as follows:

$$\text{Simulated unit cost} = ((TOC_m + LC + MC) / X) \tag{14}$$

6. SIMULATION ANALYSIS AND RESULTS

We use the following set of data. The labor and material costs, and the mean and the standard deviations for the current as well as the other order are as follows:

$$\mu_c = 15000, \quad \sigma_c = 500, \quad \mu_o = 25000, \quad \sigma_o = 1000, \quad LC = \$500000, \quad MC = \$400000.$$

The data regarding activity lists, activity rates, cost drivers and activity requirements for the current as well as the other order has been presented in Table I.

Table I: Activity based data (Part 1).

Activity cost pool	**Parameter**	**Value**	A_i
R & D	Budgeted Pool Cost: $	1,000,000	2 person years
	Cost Driver:	Person years	
	Activity Rate R_{ci}: $/person-yrs	125,000	
	Activity Rate R_{oi}: $/person-yrs	100,000	
Machine setups	Budgeted Pool Cost: $	400,000	1,000 setups
	Cost Driver:	# of setups	
	Activity Rate R_{ci}: $/setup	20	
	Activity Rate R_{oi}: $/setup	15	
Training	Budgeted Pool Cost: $	100,000	90 days
	Cost Driver:	# of days	
	Activity Rate R_{ci}: $/days	400	
	Activity Rate R_{oi}: $/days	300	
Transportation	Budgeted Pool Cost: $	250,000	200,000 miles
	Cost Driver:	miles	
	Activity Rate R_{ci}: $/mile	0.4	
	Activity Rate R_{oi}: $/mile	0.4	

Table I: Activity based data (Part 2).

Activity cost pool	**Parameter**	**Value**	$\boldsymbol{A_i}$
Travel	Budgeted Pool Cost: $	180,000	100 visits
	Cost Driver:	visits	
	Activity Rate R_{ci}: $/visit	400	
	Activity Rate R_{oi}: $/visit	500	
Quality	Budgeted Pool Cost: $	150,000	2,000 inspections
	Cost Driver:	inspections	
	Activity Rate R_{ci}: $/inspection	10	
	Activity Rate R_{oi}: $/inspection	8	
CNC Programming	Budgeted Pool Cost: $	50,000	1,500 hours
	Cost Driver:	program hrs	
	Activity Rate R_{ci}: $/hr	10	
	Activity Rate R_{oi}: $/hr	12	
Inventory	Budgeted Pool Cost: $	300,000	20 SKU
	Cost Driver:	# of SKUs	
	Activity Rate R_{ci}: $/SKU	6000	
	Activity Rate R_{oi}: $/SKU	5000	
Tooling	Budgeted Pool Cost: $	500,000	200 tools
	Cost Driver:	# of tools	
	Activity Rate R_{ci}: $/tool	400	
	Activity Rate R_{oi}: $/tool	300	

First, we simulate the unit manufacturing cost for 100 different simulation runs (a sufficient sample size) using the procedure developed in section 5. The actual unit manufacturing costs from these 100 simulation runs has been presented in Table II. The average actual cost from these simulated scenarios has been found to be $129.71.

Table II: Simulated unit manufacturing costs from 100 simulation runs.

131.32	128.29	126.56	127.43	132.76	130.99	128.47	130.10	134.48	129.93
132.29	130.03	128.71	130.69	128.25	128.74	129.11	129.83	131.46	128.08
127.73	129.68	133.51	125.71	130.30	131.87	128.14	130.62	128.66	133.86
130.46	132.28	129.53	126.98	134.10	128.71	130.75	131.89	126.42	134.89
127.41	128.86	133.26	131.74	127.92	129.56	129.52	129.61	129.11	131.72
129.59	133.09	132.25	126.84	130.07	131.69	131.85	128.51	130.76	126.51
128.88	124.69	128.52	128.60	129.41	127.62	132.88	127.34	128.98	129.66
126.87	130.12	129.16	129.24	125.19	133.65	133.17	129.31	131.57	129.56
128.23	126.27	129.89	126.92	130.43	128.92	124.38	127.29	130.23	130.66
128.04	129.89	131.33	130.64	131.07	127.92	130.80	130.95	127.32	127.57

Next, we apply the data set to the cost model presented in eq. (7) and eq. (8) which results in a unit manufacturing cost of $129.7083 which is quite close to the average simulated cost of $129.71. This suggests that on an average the suggested model gives reasonable results under potential what-if scenarios.

Table III: Cost results from the model.

Activity cost pool	Budgeted costs	Under-utilization costs, UC_i	Percentage under-utilized cost
R & D	$1,000,000	$416666.70	41.67
Machine set-ups	$400,000	$19000.00	4.75
Training	$100,000	$36666.67	36.67
Transportation	$250,000	$56666.67	22.67
Travel	$180,000	$103333.33	57.41
Quality	$150,000	$5000.00	3.33
CNC Programming	$50,000	$13333.33	26.67
Inventory	$300,000	$20000.00	6.67
Tooling	$500,000	$416666.70	83.33

The budgeted and underutilization costs for different activities needed to process the current as well as other order are listed in the second and third column of Table III. The underutilization cost as a percentage of budgeted cost is also presented in the last column of Table III. The second objective of this paper involves analyzing the percentage under-utilization of cost in order to identify the potential bottlenecks. A review of the last column of Table III indicates that quality, machine setup and inventory costs are slightly under-utilized suggesting that these activities are running close to their allocated capacity. These activities and their associated resources are likely to be the bottlenecks in the near future. Therefore, the unused labor, capital and other common resources from non-bottleneck activities may be shifted and re-allocated to these activities. Such an approach essentially accords with the theory of constraints approach [44]. Theory of constraints approach [44] has these conceptual steps: identify bottlenecks; exploit the bottlenecks; subordinate all decisions to bottlenecks; elevate the bottlenecks and avoid the inertia. The intent of the present paper is also to identify the bottlenecks and elevate these bottlenecks by assigning them capacity from other resources that remain unused. However, the main difference lies in the fact that theory of constraint [44] suggested them as general conceptual steps or guidelines whereas the current paper provided a costing based mechanism to achieve it.

7. CONCLUSIONS AND FURTHER WORK

Traditional cost estimation methods based on volumetric measures fail to consider many hidden overhead costs. Activity based costing approach considers more detailed cost pools and hence offers a more realistic estimate of manufacturing costs. In most activity costing models, the under-utilization costs have been ignored. However, underutilization can provide important insights into potential bottlenecks which allow for a better budget re-allocation and a better resource management. The present paper considers the benefits of computing the resource under-utilization and suggests an activity based costing model along those lines. The paper also develops a simulation procedure in order to validate the proposed model. Further work may include modifying the model for different product mixes that share common resources and developing a more comprehensive under-utilization model based on the five steps on theory of constraints [44].

8. ACKNOWLEDGEMENTS

The author is grateful to the anonymous referees for their valuable feedback.

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