COST ESTIMATION MODEL FOR ADVANCED MANUFACTURING SYSTEMS

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ABSTRACT

With traditional costing methods, overhead costs have been calculated based on labour or machine hours. However, the introduction of advanced manufacturing systems is likely to minimise the labour cost content. But this is by no mean that the overhead costs are reducing. A more realistic cost estimation model, which is presented in this paper, uses an idea of Activity-Based Costing (ABC) by grouping various costs into their cost centre. This will tackle the wrongful use of traditional cost allocation methods and will be not only beneficial for developing a more accurate estimation of production costs but also as a tool to evaluate system performances when ones try to justify choices of systems or policies to be introduced.

1. INTRODUCTION

Today a serious industrial challenge faces manufacturers both domestically and internationally. And in response to the ever-growing competition, many manufacturers have been forced to reassess their production system and search for new ways to produce higher quality products while reducing operating costs. Although potential benefits of advanced manufacturing systems such as just-in-time (JIT), flexible manufacturing systems (FMS) are well-known, traditional costing methods, with their overemphasis on short term savings in direct manufacturing costs, cause these projects to be rejected while others fail to come up to expectations.

2. COST OF BUILDING A PRODUCT

Products built in a manufacturing organisation have three cost variables: materials, labour, and overhead. The materials variable is the cost of the material used to build the product. The labour variable is the hours invested in assembling and testing the product. overhead is everything required to support the factory while it builds the product. Thus, Overhead may include utility costs, the rent of the building, and the cost of money invested in the inventory.

With a few exceptions, the material content of the product is the biggest portion of the cost of a product. The second is overhead, with direct labour the smaller of the three. In manufacturing, all three variables have to be managed in order to achieve the lowest cost without compromising the quality of products delivered to the customers. Figure 1 presents traditional classification of manufacturing costs.

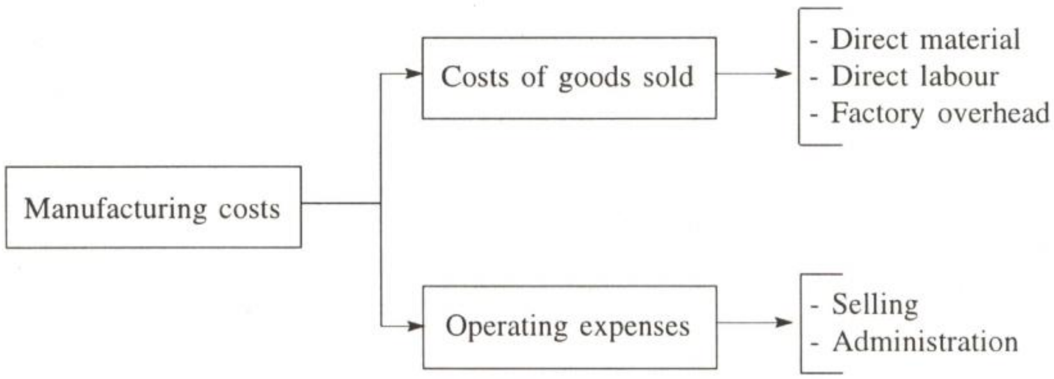

Figure 1 Traditional classification of manufacturing costs

In a typical manufacturing organisation, the arrival and flow of parts on the factory floor occurs with a certain degree of randomness. There are slippages on the suppliers' production and shipping schedules. There are delays as a result of not ordering the parts with proper lead times. In order to synchronise all these variables, manufacturers use buffer inventories as a safety measure to ensure that parts are available when needed. As a result of this, buffer inventories sprout and grow practically everywhere in the manufacturing process to cover for the above deficiencies. Advanced manufacturing systems, especially JIT, call for the reduction or elimination of all buffer inventories to save cost associated with carrying the material and to avoid the possibility of material obsolescence. However, this cannot be monitored with traditional costing methods. Without the reduction of labour and machine hour contents, overheads will be arbitrarily maintained in spite of a large amount of inventory reduction. Thus, benefits of introducing these systems connot be reflected under such an evaluation.

3. CONSTRUCTION OF COST ESTIMATION MODEL

To provide a basis for developing a realistic cost estimation model, some sources of empirical information need to be reviewed. Son [4] developed the cost model to compare the old plant with the new robotic cellular system. But, many aspects such as choices of production systems and details of shop policies are not considered in the model. Suresh [5] also uses cost model to evaluate multi-machine system investments. However, the intention of her model seems to be only to use it in a specific case. Boucher and Muckstadt [1] developed a cost estimating model for evaluating the conversion from a function manufacturing layout to the group technology layout (GT). Some interesting points can be drawn from their simple model. But, the value of a job waiting in a queue is an average value rather than an incremental value of the time spent in the queue which is updated continually through the most recent operation completion. By this way, the value of job waiting can be estimated more accurately.

To tackle the problems mentioned above, overhead costs are broken down to individual costs generated by each activity under the proposed cost estimation model. Porter [3] said activities consume resources and product consume activities in which this is the fundamental assumption of activity based costing (ABC). Thus, a cost is incurred at the point where the activity takes place. In this instance, a job which has relatively low volume but requires more special set-up or handling would result in more costs in its overhead.

With the reduction of labour cost content under the advanced manufacturing systems, labour accounting should be eliminated and assigned into overhead costs. Given that labour is treated as part of overhead, there are, of course, only two elements in product costs-materials and overhead - and labour hours/costs are not available as based for overhead recovery. Hewlett-Packard's UK plant has been successfully implemented this idea in abandoning direct labour accounting [2].

Since ABC cannot identify costs incurred from non-valued added activities. Opportunity cost's concept is introduced to take account of measuring costs and benefits of these activities. In economic analysis, an opportunity cost can be defined as the potential profit that is lost or sacrified when the choice of action requires the giving up of an alternative cost of action [4]. With the non-valued added activities of work-in-process waiting on a shop floor or idle time of machines, there are certain benefits that are foregone as a result of these activities taking an action. Figure 2 show proposed classification of total manufacturing costs under advanced manufacturing systems.

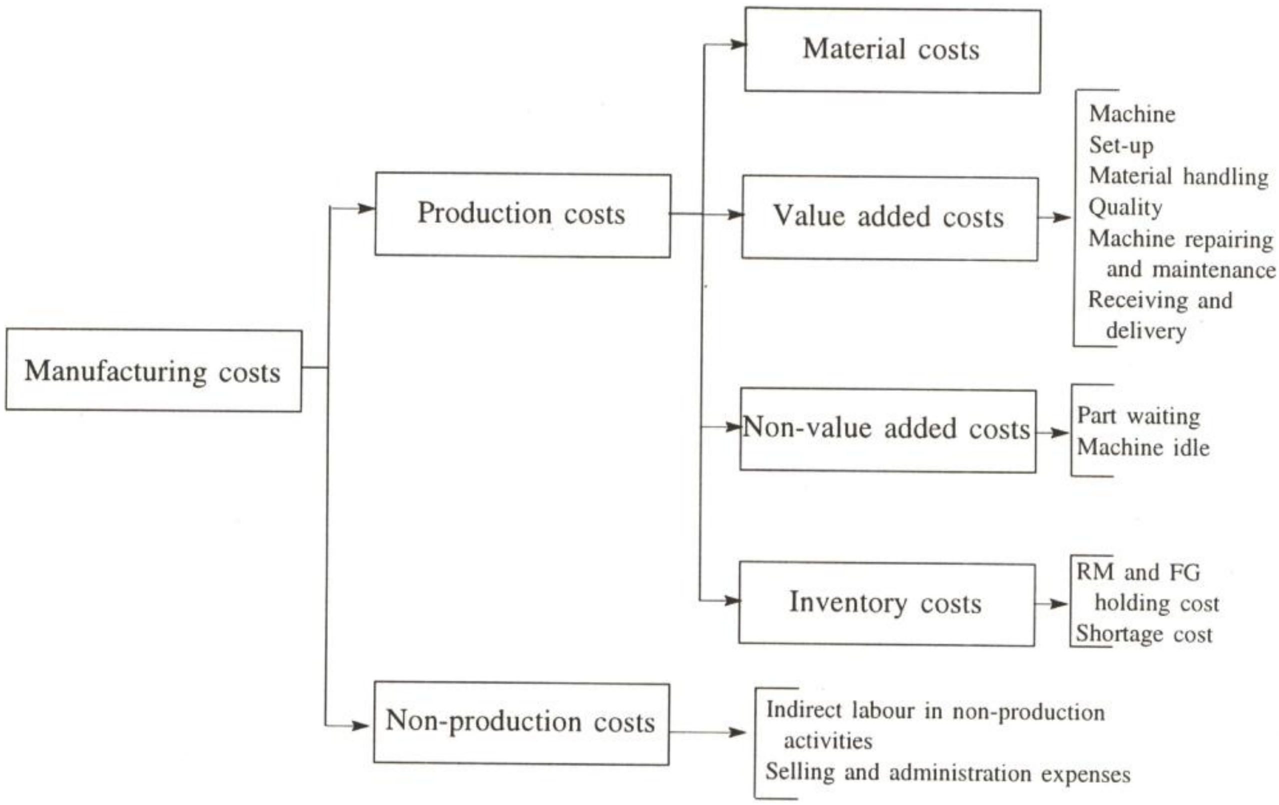

Figure 2 Proposed classification of total manufacturing costs under advanced manufacturing systems

3.1 Production costs

According to the new classification, production costs include material cost, valued added and non-valued added overhead costs and inventory cost. Since the interest in production processes is the main focus in this paper, only the production cost will be mentioned.

3.1.1 Material cost

Materials are main components which transformed into finished product through the use of labour and factory overhead in the production process. Material costs consist of direct and indirect materials. As their names imply, direct materials are all materials that can be easily traced to the product and represent a major material cost of producing that product whereas indirect materials involve in the production of a product that are not direct materials and used to be included as part of overheads.

Material cost (M)

= (unit cost of direct material)(amount of direct material used) + indirect materials' expenses

$$= \Sigma^{P}_{p=1}[UC_p * AM_p] + IM$$

where

UC_p = cost per unit of direct material for product p (baht/unit)

AM_p = amount of direct material used for product p (unit)

IM = indirect materials' expenses

P = number of different products

3.1.2 Value added costs

3.1.2.1 Machine cost

Machine cost consists of direct labour cost using to operate machines as well as machines utility cost, both electricity and fuel. Traditionally, the machine cost is based on direct labour or machine hours. But nowadays, advanced manufacturing system innovates to use the automated machines which are easy to measure the working hours of machines. As a result, the machine cost can be calculated more quickly and reliably. Under some assumptions such as that direct labours handle both running machines and setting up activities but indirect labours may help setting-up activities, machine cost during planning period may be presented by:

Machine cost (CM)

= (machine cost per unit time) (total machine time of machines)

$= \sum^{P}_{p=1}\sum^{K}_{k=1}[MC_p(k) * TM_p(k)]$

where

$MC_p(k) = [DL_p(k) + EC_p(k)]$

$MC_p(k)$ = machine cost per unit time of machine p for product k (baht/unit time)

$DL_p(k)$ = direct labour cost per unit time of machine k for product p (baht/unit time)

$EC_p(k)$ = utility cost per unit time of machine k for product p (baht/unit itme)

$TM_p(k)$ = total machine time of machine k for product p during planning period (unit time)

K = number of different machines

3.1.2.2 Set-up cost

Set-up cost is the cost of preparing machines for each production run. It includes direct labour and indirect labour costs during set-up. Then, the set-up cost during planning period is:

Set-up cost (CS)

= (set-up cost per unit time) (total set-up time)

$= \sum^{P}_{p=1}\sum^{K}_{k=1}[SC_p(k) * TST_p(k)]$

where

$SC_p(k) = [DL_p(k) + IDL_p(k)]$

$SC_p(k)$ = set-up cost per unit time of machine k for product p (baht/unit time)

$IDL_p(k)$ = indirect labor cost per unit time during set-up of machine k for product p (baht/unit time)

$TST_p(k)$ = total set-up time of machine k for product p during planning period (unit time)

3.1.2.3 Material handling cost

Material handling cost is the cost for transporting the parts of the product. There are many ways of transporting an item from one place to another place ranging from forklift truck to conveyor. Then, the material handling cost is calculated by:

Material handling cost (CMH)

= (transportation cost per unit time) (total transportation time)

$= \sum^{P}_{p=1}\sum^{K}_{k=0}\sum^{R}_{r=1}[TC_p(k,r) * TT_p(k,r)]$

where

$TC_p(k,r)$ = transportation cost per unit time of product p at machine k by transporters r (baht/unit time); $k = 0 \Rightarrow$ warehouse

$TT_p(k,r)$ = total transportation time of product p at machine k by method r during planning period (unit time)

R = number of different types of transporters

3.1.2.4 Machine repairing and maintenance cost

When a machine is broken down, it needs to be repaired in which the cost of this repairing should be included in the production cost. Additionally, machines have to be maintained by stage; weekly, monthly, annually, etc. Then, the machine repairing and maintenance cost is:

Machine repairing and maintenance costs (CRM)

= (repair cost per unit time) (total repairing time) + (maintenance cost per unit time)(total maintenance time)

$= \Sigma^{K}_{k=1}[MRC(k)* TRC(k)] + \Sigma^{K}_{k=1}[MMC(k)* TMC(k)]$

where

$MRC(k)$ = repairing cost per unit time of machine k (baht/unit time)

$TRC(k)$ = total repairing time of machine k during planning period (unit time)

$MMC(k)$ = maintenance cost per unit time of machine k (baht/unit time)

$TMC(k)$ = total maintenance time of machine k during planning period (unit time)

3.1.2.5 Receiving and delivery costs

Receiving cost is the cost of ordering and receiving order when raw materials are ordered and purchased. Delivery cost is the cost of delivering finished products to customers. Receiving and delivery costs include transportation cost, direct labour, and indirect labour involving in these activities.

Receiving and delivery costs (CRD)

= (receiving cost per batch) (number of received batches during planning period) + (delivery cost per delivery batch) (number of delivery batches during planning period)

$= \Sigma^{P}_{p=1}[RC_p * NRC_p + DC_p * NDC_p]$

where

RC_p = cost of receiving order per received batch during planning period of product p (bath/batch)

NRC_p = number of received batches of product p during planning

DC_p = delivery cost per delivery batch of product p during planning period (baht/batch)

NDC_p = number of delivery batches of product p during planning period (batch)

3.1.2.6 Quality cost

Quality cost has been used as a financial control tool for management and identify opportunities for reducing quality costs and are associated with producing, identifying, avoiding or repairing products that do not meet the specifications. As suggested by Son [4], quality costs can be considered into two groups; prevention cost and failure cost. Prevention cost is the cost of preventing defective (finished) product through checking and correcting in-process quality problems before final inspection and, therefore, combines conventional appraisal and prevention costs. Basically, it is concerned with studies of control charts (CC) and process capability (PC). Failure cost is the loss due to failure of finished products to meet quality standards set by both a company and customers, and combines conventional internal failure and external failure costs. It is concerned with final inspection. With the limitation of space provided, more details of quality cost can be seen from [4].

3.1.3 Non-value added cost

3.1.3.1 Machine idle cost

Machine idle cost is a cost associated with the under-utilisation of machines. Opportunity cost can be used to estimate this cost. Its cost per unit time can be considered in two ways depending on market conditions. If there is demand, make-to-order, they may be considered as lost profits because opportunities of making and selling more products are foregone. In this case, opportunity cost per unit time is based on the profit margin or profit rate. If there is no demand, make-to-stock, they may be considered as capital tied up in machine and work-in-process inventory. In this case, opportunity cost per unit time is based on the company or project's rate of return. Then, the machine idle cost is:

Idle cost (CI)

= (opportunity cost per unit time) (total value of idle time of machine)

$$= \upsilon * \sum_{k=1}^{K} [1-U(k)] * T * \varepsilon * P(k) * O(k)]$$

where

υ = cost of capital (project's rate of return) ; *if make-to-stock*

= profit rate (profit margin) ; *if make-to-order*

$U(k)$ = % utilisation of machine k

T = total time during planning period (unit time)

ε = efficiency allowance of remaining time

$P(k)$ = present value of machine k (baht)

$O(k)$ = depreciation rate of machine k (baht/unit time)

3.1.3.2 Waiting cost

Waiting cost is a cost associated with products that are waiting for service somewhere in the manufacturing processes. It can also be considered as the cost of work-in-process inventory. There are two kinds of waiting costs that are *process waiting cost* when parts or products queue in front of machines and *batch waiting cost* occurring when a product completes the machine but waits for the completion of its batch size.

For each job, a WIP contribution is the increment of the time spent in queue multiplied by the corresponding value added through the most recent operation completion. Like the idle cost, two situations are classified for this cost that are make-to-stock and make-to-order. Waiting cost can be calculated by;

Process waiting cost

= (opportunity cost per unit time)(total value of waiting time before parts can be processed)

$= \upsilon * \sum^{P}_{p=1} \sum^{kj}_{k=1} \{[UC_p + \sum^{kj}_{k=1} [(CM_p(k\text{-}1) + CS_p(k\text{-}1) + CMH_p(k)) / ((NB_p(k) * BS_p(k))]] * TP_p(k)\}$

Batch waiting cost

= (opportunity cost per unit time)(total value of waiting time before a product can complete its batch size)

$= \upsilon * \sum^{P}_{p=1} \sum^{kj}_{k=1} \{[UC_p + \sum^{kj}_{k=1} [(CM_p(k) + CS_p(k) + CMH_p(k)) / ((NB_p(k) * BS_p(k))]] * TB_p(k)\}$

where

$NB_p(k)$ = number of batches of product p at machine k (batch)

$BS_p(k)$ = batch size of product p at machine k (unit/batch)

$TP_p(k)$ = total waiting time in queue before product p enters machine k (unit time)

$TB_p(k)$ = total waiting time in queue after product p finishes machine k (unit time)

k_j = number of machines that product p visits

3.1.4 Inventory cost

Inventory cost is the combination between the cost of carrying and lacking raw materials and finished products. Inventory here only includes raw materials and finished products since work-in-process is accounted in waiting cost. However, same product type cannot have the holding cost and shortage cost at the same time.

Inventory cost (CI)

= holding cost + shortage cost of raw materials and finished products

= (holding cost per unit) (number of units held in warehouse) + (shortage cost per unit) (number of units shortage)

$= \sum^{P}_{p=1} [MHC_p * (IM_p + SM_p - WM_p) + FHC_p * (IF_p + Q_p - D_p)] + \sum^{P}_{p=1} [MSC_p * (WM_p - SM_p - IM_p) + FSC_p * (D_p - Q_p - IF_p)]$

where

MHC_p = cost of holding a unit of raw material of product p during planning period (baht/unit)

FHC_p = cost of holding a unit of finished product p during planning period (baht/unit)

MSC_p = the shortage cost of a unit of raw material of product p during planning period (baht/unit)

FSC_p = the shortage cost of a unit of finished product of product p during planning period (baht/unit)

IM_p = the initial inventory of raw materials for product p (unit)

SM_p = the amount of raw materials for product p obtained from suppliers during planning period (unit)

WM_p = the amount of raw materials for product p delivered into production processes during planning period (unit)

IF_p = the initial inventory of finished product p (unit)

Q_p = the amount of product p produced during planning period (unit)

D_p = the demand rate for product p during planning period (unit)

4. CONCLUSIONS

This paper presents a small step towards measuring quality and flexibility which are the main improving area for introducing advanced manufacturing systems. This step involves a big risk because they are intangible, ill-structured, and entail considerable time for recognisable results. However, with the ill-structure of traditional costing methods, many benefits of advanced manufacturing systems cannot be detected and this results in the productivity paradox and failure to justify these new systems. The proposed cost estimation model expands the cost concept breaking overhead costs according to their cost centre and introduces opportunity cost to estimate the neglected cost of non-value added activities. This will present a more realistic cost model that should be used to estimate production costs more accurately. The project is also extended to include the use of simulation tool for providing data for verification of the cost model developed.

5. REFERENCES

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