A Study on Optimal Evaluation Model for FMSs Using Activity-Based Costing

- 활동원가를 이용한 FMS의 최적 평가모델에 관한 연구 -

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요 지

전통적인 원가계산 시스템에서 원가의 정확성은 생산량의 증감에 따라 변동하는 제조간접비에 의존하게 되며, 원가 배부기준은 대부분 생산하고 있는 제품의 수량과 밀접하다. 그러나, FMS 혹은 CIM등의 고도로 발달한 제조환경에서의 제조간접비는 반드시 생산량에 비례하지 않는다. 즉, 제품원가 구조변화 및 생산의 복잡성과 다양성에 따른 기업환경 변화등이 주원인이 될 수 있다. 따라서 본 연구에서는 ABC 원가계산 시스템과 LP Model에 의한 전통적인 원가계산 방식과는 다른 ABC 원가계산 시스템을 만들었으며, 원가 활동동인에 따라 생산성 및 생산성 향상, 최적투자 활동등을 수행할 수 있는 FMS 생산시스템의 최적평가 Model을 구축하였다.

1. Introduction

Many companies need to invest in an advanced manufacturing systems to survive viable in highly competitive market area. The investment in a flexible manufacturing systems(FMSs) changes a company's entire manufacturing processes and eventually, the cost structure of those processes. In general, the investment in a FMS significantly reduces direct costs and greatly increases overhead costs as shown in Fig. 1.[6]

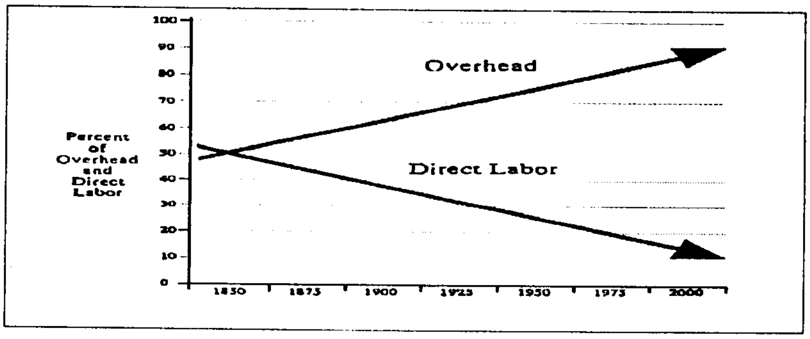

Fig. 1. The change in cost structure of manufacturing systems

Under this cost structure, labor-based traditional cost accounting(TCA) systems fail to signal the actual overhead cost incurred in a manufacturing systems of today. In a FMS, the diversity of production can limit the application of TCA systems. Since such systems can not keep pace with changes in manufacturing technology. Therefore, companies need to develop new cost accounting systems to reflect these changes occurring in manufacturing environment. As shown in Fig. 2,[6] complexity, variety, and diversity in businesses have escalated dramatically. An increasingly complex manufacturing environment leads to higher

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overhead cost.

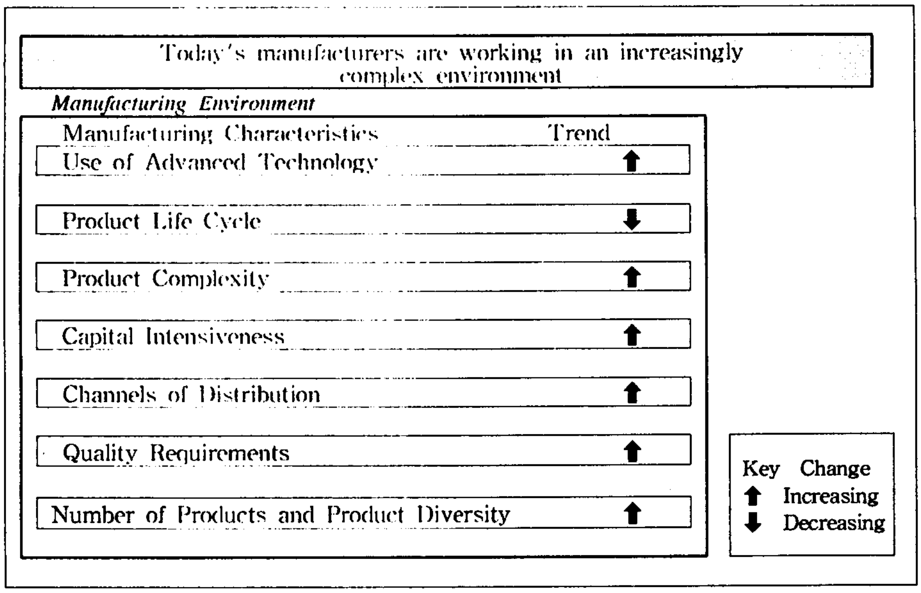

Fig. 2. Current business environment

New cost accounting systems need to meet at least three requirements to be useful in justifying the investment of FMS. First, since the investment justification is based on many elements of accounting data, they need to generate an accurate and reliable product costs. Second, they need to take a full account of potential savings and benefits for the investment project under consideration. Third, they need to enable managers to quantify indirect savings / costs and intangible benefits such as quality improvement and manufacturing flexibilities. Since today's manufacturing excellence goes beyond traditional measures such as reduction in direct labor cost and direct material cost. In an effort to address some of these requirements, activity-based cost(ABC) system have been proposed. Most research with ABC system, to date, has been dedicated to identifying and pricing the activities associated with manufacturing a product.

2. Literature review on ABC System

To survive in today's competitive market environment, companies must be capable of manufacturing products of high quality at low cost and also deliver them to customers at the right time. Many companies have recently responded to competition by investing in a FMS and emphasizing quality, delivery and flexibility to meet customer's requirement in their objectives. TCA systems allocate overhead costs to products based on production volume-related attributes(e.g. direct labor cost, machine time or direct material cost) in a manufacturing of a narrow range of products. ABC systems have been proposed as one of the alternatives to improve many of the short-comings of the TCA systems assuming that manufacturing activities consume resources, and that products demand the manufacturing activities.[10] ABC systems trace the costs of resources actually consumed to those activities in the first stage and then to products using the cost drivers identified for activities in the second stage(called "usage" model). Fig. 3 shows the relationship between cost assignment and products in ABC systems.

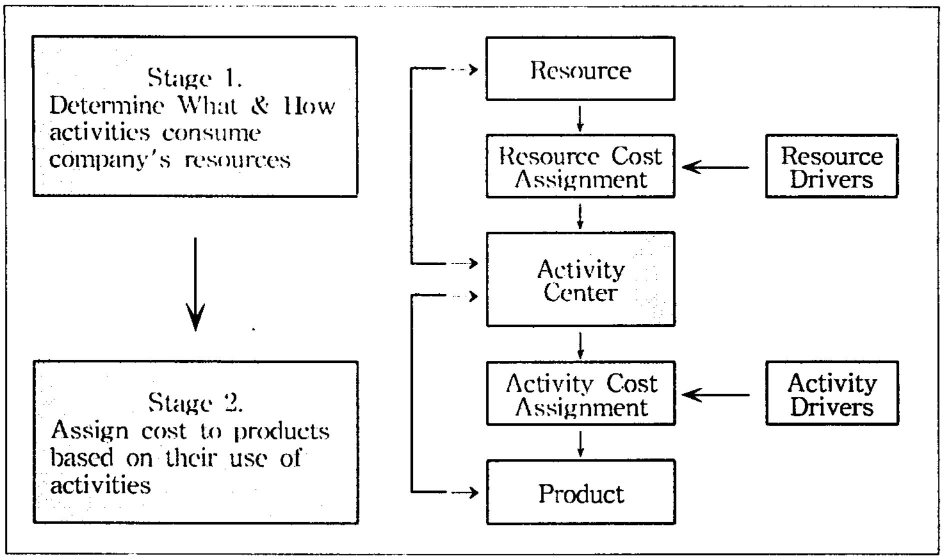

Fig. 3. Tow-stage cost assignment to products in ABC systems.

Cooper and Kaplan[9] present to characteristics of ABC system as follows. First, ABC systems reflect in product costs only the portion of resources actually used. The remaining unused portion is treated as a period expense. Second, practical capacity is used as the denominator to calculate the unit cost of the activity. Also, Smith and Leksan[10] show how an ABC system can lead to more effective decision marking regarding product pricing and profitability, capital investment justification and performance measurement. Recently, many authors have mentioned new performance measurement systems in relation to ABC systems and presented the various methodologies justifying investment in an advanced manufacturing technology since FMSs emerged as promising manufacturing systems. According to the assumption of ABC systems, costs are caused by activities because the activities consume a company's resources. With ABC system, cost are managed by controlling the activities which derive them. In other words, managers are forced to view operations as the management of activities, not cost. Thus, measuring, analyzing and monitoring the performance of the activities have a close relationship with obtaining a high profitability. Later, Mills, R. W.[14] develop a multistage investment decision model that explicitly considers these nonconventional costs. In this decision model, they treat all costs associated with these flexibilities as opportunity cost and thus incorporate these costs into after-tax cash flows. Even though the basic logic behind dealing with manufacturing cost in is very similar to the logic of ABC systems, their model is largely based on the traditional accounting systems.

3. Proposed cost classification under ABC system.

To understand the characteristics of each accounting system, We will compare TCA to ABC systems and examine a product costing procedure under ABC systems. A typical structure of an income statement in TCA systems is shown in Table 1. In reporting an operating income, net sales represents the gross sales less any sales returns and allowances. Shown on the several lines are expenses, and costs of doing business as

Total Expenses	Cost of Goods sold	Factory Cost	Direct Labor
			Direct Materials
			Overhead
		Inventory	Raw Materials
			Finished Goods
		Depreciation	
	Operating Expense	Selling	
		Administrative	
	Non-operating Expense	Interest Expenses	
		Miscellaneous Expenses	
	Income Taxes		
Net Income = Total Revenues - Total Expenses			

Table 1. Income statement in TCA systems

deductions from the revenues. Note that factory overhead costs are put into one cost element of "overhead costs". Operating expenses are excluded from the cost of goods sold. Table 2 shows the proposed structure of an income statement under ABC systems. In this structure, we classify total expenses into material, direct labor, various manufacturing activities, non-activities, non-operating costs, depreciation and income tax expenses. The first two costs are supplied as needed, while the rest are supplied in advance of usage. The operating expenses in TCA systems disappear in ABC structure.

Total Expenses	Direct Materials, Direct Labor		
	Activity Expenses	Processing Activity	
		Tooling Activity	
		Setup Activity	
		Quality Control Activities	Prevention Activity
			Appraisal Activity
			Internal Failure Activity
			External Failure Activity
		Inventory Handling Activity	Storage Activity
			Fork lifting Activity
		Material Moving Activity	
		Purchasing Activity	
		Computer Software-Related Activity	
		Other Activities	
	Depreciation		
	Non-Activity Expenses	Waiting Time Activity	
		Idle Time Activity	
		Inventory Holding Activity	
		Unused Activity	
	Non-operating Expenses	Interest Expenses	
		Miscellaneous Expenses	
	Income Taxes		
Net Income = Total Revenues - Total Expenses			

Table 2. Proposed income statement in ABC systems

In TCA systems, these expenses are treated as a "period expense", but are assigned to products in ABC systems. The cost element of "other activities" may be service-rated activity costs such as sales, marketing and administrative costs. As shown in Table 2, there are non-activity costs which are not directly involved in activities performed for products. They are cost associated with unused activity, waiting time, idle time and inventory holding. Fig. 4 depicts the conceptual structure of ABC systems for the processing activity cost assignment described as belows.[7,9]

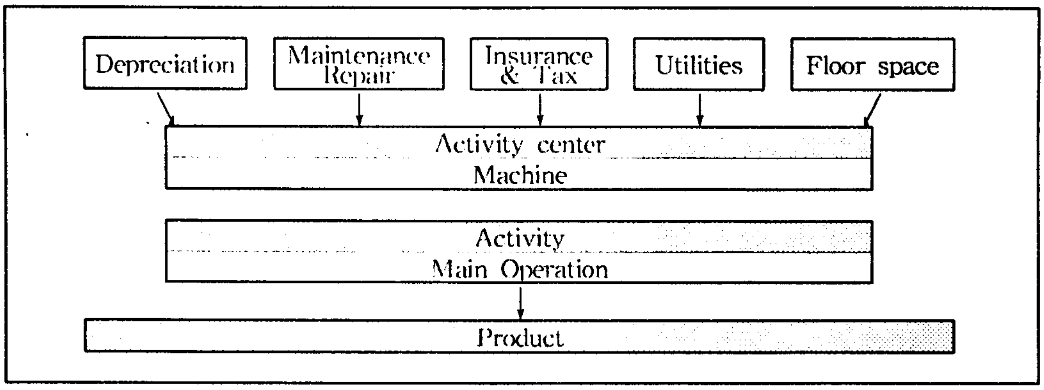

Fig. 4. Conceptual structure of ABC systems for the processing activity cost assignment.

Here, unused activity costs are defined as the remaining portion of activity expenses not assigned to products due to over-capacity. Among non activity costs, waiting time and idle time are usually considered "opportunity cost". So, the major differences between TCA and ABC systems are shown in Table 3.

Factors	TCA systems	ABC systems
Main purpose	Financial reporting	Product costing
Cause of costs	Products	Activities
Cost driver	Labor hours, Material cost or Machine hours	As many as needed
Cost classification	Fixed and variable costs	Variable costs
Expenses	Fully absorbed	Partially absorbed
Capacity Expenses	Budgeted production volume	Practical capacity
Depreciation	Straight-line	Machine hour-usage
General, Administrative, Marketing & Selling Expenses	A period expenses	Assigned to products
R & D Expenses	A period expenses	A period expenses or assigned to products

Table 3. Differences of TCA and ABC systems.

Cooper[10] suggests that the number of cost drivers should be determined subject to the desired accuracy of product costs and based on the complexity of the product mix. We will follow Cooper and Kaplan's work[11] by splitting R&D expenses into two categories. With this division, the first category should be traced to the products that will benefit from the development effort. Otherwise, the cost will be distributed to products and lines that bear no relationship to the applied R&D program. For the Second category, we also teat the costs as investments in the future.

4. Modeling Activities Based Costing Systems

4-1. A Multiperiod LP Model

A multiperiod Linear Programming(LP) model is considered for ABC systems with costs as denoted in Table 4. Material cost and direct labor cost are charged as needed. Waiting time, idle time and unused activity cost are non-activity costs. In ABC systems, a company must first identify activities performed to manufacture products. The major activity performed by a company's resources obey the following relationship:

Activity Availability - Activity Used + Unused Activity Capacity

The measurement of unused activity capacity provides the critical link between the costs of resources used, as measured by the ABC model and the costs of resources supplied or available, as reported by the company's financial statements. Thus, the unused activity capacity costs must be subtracted from a company's profit. In order to subtract the cost of the unused activity capacity constraints in the LP model will hold with equality.

Notation	Description
j	Product index, j=1,2, · · · · ,N
k	Activity index, k=1,2, · · · · ,K
t	Project planning horizon, t=1,2, · · · · ,T
C_{1jt}	Material cost
C_{2jt}	Direct labor cost
C_{3jt}	Processing activity cost
C_{4jt}	Tooling activity cost
C_{5jt}	Setup activity cost
C_{6jt}	Purchasing activity cost
C_{7jt}	Material moving activity cost
C_{8jt}	Prevention activity cost
C_{9jt}	Appraisal activity cost
C_{10jt}	Internal failure activity cost
C_{11jt}	External failure activity cost
C_{12jt}	Computer software-related activity cost
C_{13jt}	Waiting time activity cost
C_{14jt}	Idle time activity cost
C_{15jt}	Inventory activity cost
C_{16jt}	Unused activity cost

Table 4. Description of Variables and Activity Costs

The variable C_{16jt} represents the total unused activity capacity cost. It is noted that this cost is equal to the sum of the unused capacity costs of all activities multiplied by each activity unit cost. In a TCA model, unused capacity is not considered as a period cost, but in an ABC system this assumption is no longer valid. In the table 5, W_{jt} represents after-tax opportunity costs such as waiting and idle time activity cost. To implement the model, in general, we need to collect data on the estimates of annual market demand, a company's activity capacities, manufacturing costs, opportunity costs and inventories. It is assumed that back-ordering is not permitted in this production system. With this in mind, the primal(P) is formulated based on the after-tax cash flow approach. The complete mathematical model for investment decision model under ABC systems may be summarized as below.

$$\text{Max. NPV} = \text{Revenues} - \left\{ \left| \begin{array}{c} \text{Direct Labor,} \\ \text{Direct Material} \\ \text{Activity Cost} \end{array} \right| + \left| \begin{array}{c} \text{Inventory Costs,} \\ \text{Unused activity} \\ \text{Cost} \end{array} \right| + \left| \begin{array}{c} \underline{\text{Opportunity Cost}} \\ \text{Waiting Time Cost,} \\ \text{Idle Time Cost} \end{array} \right| \right\}$$

subject to

- Resource constraint for Activities
- Resource constraint for Inventory - Related Activities
- Production / Inventory / Demand Balance Equation
- Unused Activity cost
- Nonnegativity constraints

and its mathematical expression as follows.

(P) Max NPV

$$= \sum_{t=1}^{T}\sum_{j=1}^{N}(1-t_{m})[P_{jt}(Q_{jt}+I_{jt-1}-I_{jt})-C_{jt}Q_{jt}-C_{15jt}I_{jt}-C_{16t}-W_{jt}Q_{jt}](1+i)^{-t} \quad \text{-------(1)}$$

Subject to

$$\sum_{j=1}^{N}R_{kjt}Q_{jt}+U_{kt}=A_{kt} \quad \text{----(2)}$$

$$\sum_{j=1}^{N}R_{15jt}I_{jt}+U_{15t}=A_{15t} \quad \text{-----(3)}$$

$$Q_{jt}+I_{jt-1}-I_{jt}=D_{jt} \quad \text{-----(4)}$$

$$C_{16t}-\sum_{k=1}^{15}C_{kt}U_{kt}=0 \quad \text{-----(5)}, \quad \text{Where } Q_{jt}, I_{jt} \text{ and } U_{kt} \geq 0$$

The variables used in the LP model described as belows.

Variable	Description
A_{kt}	Availability of activity k at time t
C_{jt}	Manufacturing cost of product j at time t
C_{kt}	Unit cost of activity k at time t
C_{kjt}	Unit cost of activity k for product j at time t
i	Minimum attractive rate of return
D_{jt}	Demand for product j at time t
I_{jt}	Inventory level of product j at time t
P_{jt}	Selling price of product j at time t
Q_{jt}	Quantity of product j at time t
R_{kjt}	Level of activity k for product j at time t
U_{kt}	Unused capacity of activity k at time t
W_{jt}	Opportunity cost for product j at time t

Table 5. Description of the variables

Eq.(1) is the objective function for a company to maximize its discounted after-tax cash flows associated with products and scarce activity capacities. Eq.(2) is an activity capacity constraint where the first and second terms represent the consumption level of the activity capacity required by the products and the unused activity capacity which is not required by the products. The right hand side, A_{kt}, is the total amount of an activity capacity available, (3) is separated from the other activity constraints. Eq.(4) is a demand-supply equality constraint; the annual demand quantity, D_{jt}, is satisfied with the production quantity of product, Q_{jt} and the inventory of the product during the previous period, I_{jt-1}. After satisfying the current year demand, there may exist inventory of the product for the current period, I_{jt}, if $Q_{jt}+I_{jt-1} > D_{jt}$. Eq.(5) is a constraint of an unused activity capacity. The initial state of the production system is fixed by zero inventory level for all products and the ending state of inventory is also set to zero.

By eliminating the I_{jt-1} term, the objective function can be rewritten as

$$\text{Max NPV} = \sum_{j=1}^{N}\Big[\sum_{t=1}^{T}[(1-t_m)(P_{jt}-C_{jt})-W_{jt}]Q_{jt}(1+i)^{-t}$$
$$-\sum_{t=1}^{T-1}(1-t_m)[P_{jt}-P_{jt+1}(1+i)^{-1}+C_{15jt}]I_{jt}*(1+i)^{-t}$$
$$-(1-t_m)(P_{jT}+C_{15jT})I_{jT}(1+i)^{-T}\Big]-\sum_{t=1}^{T}C_{16t}(1+i)^{-t}(1-t_m) \text{ -----(6)}$$

and the balance equation of supply and demand (4), by a recursive substitution, becomes

$$Q_{jt}+I_{jt-1}-I_{jt}=D_{jt}=\sum_{h=1}^{t}Q_{jh}-I_{jt}=\sum_{h=1}^{t}D_{jh} \text{ --------(7)}$$

The manufacturing cost is expressed by $C_{jt}=\sum_{k=1}^{14}C_{kjt}$ --------(8)

Note that Eq.(8) does not involve inventory related cost and opportunity costs.
Opportunity cost (W_{jt}) is given as $W_{jt}=C_{13jt}+C_{14jt}$ -------(9)

4-2. Formulating the Dual LP Model

In the primal model(P), a company's scarce activities are allocated to the most profitable products based on the the highest net contribution per unit of scare activity consumed. The dual of the primal LP, formed from exactly the same data, is useful for investigating that portion of the primal objective value that is imputed to each of the activity capacities. The dual model for (P) is described as blows,

Minimize Total Accounting Value

Min. TAV = | Total Manufacturing Accounting Value | + | Total Inventory Accounting Value | + | Total Delivery Accounting Value |

subject to

- Manufacturing Accounting Value constraints
- Inventory Accounting Value constraints
- Constraint for Activity Accounting Value
- Unrestricted Accounting Value constraints

and its mathematical expression follows.

$$\text{(D) Min. NPV}' = \sum_{t=1}^{T}\Big[\sum_{k=1}^{14}A_{kt}V_{kt}+A_{15t}V_{15t}+\sum_{j=1}^{N}\Big(\sum_{h=1}^{t}D_{jh}\Big)Y_{jt}\Big] \text{---------(10)}$$

subject to

$$\sum_{k=1}^{14}R_{kjt}V_{kt}+\sum_{h=t}^{T}Y_{jh} \geq [(1-t_m)(P_{jt}-C_{jt})-W_{jt}](1+i)^{-t} \text{ -------(11)}$$

$$R_{15jt}V_{15t}-Y_{jt} \geq (1-t_m)[P_{jt}-P_{jt+1}(1+i)^{-1}+C_{15jt}](1+i)^{-t}, \text{ where } t \neq T \text{ ----(12)}$$

$$R_{15jT}V_{15T}-Y_{jt} \geq -(1-t_m)(P_{jT}+C_{15T})(1+i)^{-T}, \text{ where } t = T \text{ ----(13)}$$

$$V_{kt} \geq -C_{kt}(1-t_m)(1+i)^{-t} \text{ ------------(14)}$$

where V_{kt} and Y_{jt} are unrestricted in sign.

Eq.(10) is the standard objective function for a company to minimize the total valuation of its activity capacities which are deployed to manufacturing products. Eq.(11) is the constraint which yields the relationship between the total accounting value required to manufacture one unit of a product and the discounted after-tax unit production profit of the product. Eq.(12) is accounting value required to handle one unit of the inventory of a product for t =1, 2, 3, ---,T-1 and (13) for t T, respectively; and (14) is the constraint on the limit of activity accounting values.

4-3. Dual and Dual Slack Variables

1) Dual Variables of Activity Capacity Constraint

The dual variables associated with activity capacity constraints, V_{kt} , indicates how much of a company's profit would increase if its investment in activity k at time t were increased by on unit $V_{kt} = \triangle NPV / \triangle A_{kt}$ ------------(15)

2) Dual variable of Demand-Supply Constraints

The dual variable, Y_{jt} are the marginal amount that a company would pay to meet the demand for product j at time t.

3) Dual Slack Variables

Recall that dual slack variables represent the difference between the right-and left-hand sides of the dual constraints.

$$L_{jt} = D_{jt} - R_{jt} \quad \text{------------------(16)}$$

where, L_{jt} = the accounting loss per unit of product j at time t.

D_{jt} = total accounting value of activities going into a unit of product j at time t

R_{jt} = the discounted after-tax unit profit of product j at time t

4-4. Constraints

The complementary slackness conditions for the primal-dual problem can be written

$$Q_{jt}\, L_{jt} = 0$$

for each product j at time t, where V_{kt} is unrestricted.

1) Production Quantity

For dual constraint(11), if the accounting loss L_{jt} is positive, there is no reason to manufacturing product j at time t.

$$\sum_{k=1}^{14} R_{kjt} V_{kt} = [\,(1 - t_m)(P_{jt} - C_{jt}) - W_{jt}](1+i)^{-t} - \sum_{h=t}^{T} Y_{jh} \quad \text{----------(17)}$$

The left side of the equality in(17) is the total accounting value of the activities consumed to manufacturing one unit of product j at time t. Note that C_{jt} does not include the inventory activity cost.

2) Effective production unit profit

The effective production unit profit describes how much a true profit of products should be in terms of the internal value of a company's activity capacities.

3) Dual Variables of Demand-Supply Constraints

In this model, the accounting variable Y_{jt} has a special meaning in a relationship between inventory cost and a product selling price.

4) Unused Activity Capacity and Its Dual Constraints

Dual constraints(14) is associated with a primal variable, U_{kt} , i.e., the activity capacity associated with U_{kt} is Under-utilized.

5) Reduced cost of unused Activity Capacity Variable

The value of V_{kt} is unrestricted and can be negative, zero, or positive under current investment decision model.

4-5. Objective Function

The value of the dual objective function also has an economic interpretation. A company has A_{kt} units of activity capacity. So the total value of the activity capacity available to the firm is $A_{kt} V_{kt}$. The first term in the dual objective function(10) represents the total accounting value of all the capacities available to the company during the planning horizon, T. If the production rate equals the demand rate, i.e. $Q_{jt} = D_{jt}$, then the term $\sum_{t=1}^{T} A_{15t} V_{15t}$ become zero($I_{jt}=0$). Thus, the third term in the dual objective function consequently disappears.

4-6. Managerial Implication Of the Dual Analysis

The effectiveness of each activity can be determined in various ways such as measuring its overall performance based on quality of the work done, completion time, time to setup equipment, and resource stabilization. In today's highly competitive global market, companies struggle to increase their profit. By restructuring the work force, a company can increase short-term profit by eliminating jobs and reducing labor cost, which increases the productivity of each worker. After this is achieved, or concurrently with the restructuring, a company also tries to reduce the total manufacturing cost of products. To effectively increase profit, managers should concentrate on the activities whose accounting values are the largest negative number because they decrease profit the most. Traditionally, a company focused on resources in a descending order of accounting values. Since a negative accounting value means an over-priced unit cost of an activity capacity, managers can cut the over-priced unit cost by reducing the consumption level of the Activity. When managers determine the investment priority, they should then focus on the activities in a descending order of their accounting value. The nature of the model developed in this paper is such that a demand quantity of products is restricted, and therefore deciding whether or not to invest must be accompanied with the analysis of the demand quantity of the products.

Finally, by solving a dual LP problem, managers know the effective production unit profit of products, Π_{jt}. The effective production unit profit describes how much a true profit of products should be in terms of the internal value of a company's activity capacities. Therefore, the effective production unit profit can be either greater than or equal to, or less than the ordinary profit. Ordinary profit is the difference between a selling price and a total manufacturing cost.

5. Conclusion

The development of TCA system is based on the mass production of mature product with known characteristics and stable technology. A FMS is believed to provide a company with a fairly acceptable level of intangible benefits such as improved quality, reduced cycle time, improved flexibility, less inventory and less waiting time. To have these benefits, a company must spend a large amount of initial investment for a FMSs. Thus, if intangible benefits are not taken into account when evaluating an optimal investment project for a FMSs, these projects may turn out to be inferior to the existing traditional manufacturing system. Among the intangible benefits, time-based benefits have been considered important factors in today's manufacturing companies. Quantifying and incorporating the time-based intangible benefits such as waiting time and idle time costs into an investment justification procedure make the FMS more favorable than the batch shop system.

In this paper, ABC system is described and a multiperiod linear programming model is developed for a general investment decision problem related to FMSs. We have described the optimal evaluation model of a multiperiod LP model problem. In ABC systems, the costs of all unused activity capacities are subtracted from a company's discounted after-tax profit. The new interpretation for managers to justify a unit cost of an activity capacity determined to calculate a product cost using LP model. It is difficult to value intangible activities such as waiting and idle time activity which are critical to achieving manufacturing excellence.

As conclusion, we would note that it is very important to quantify the intangible benefits as well as to choose a proper cost accounting system. This point is a little different from the traditional belief which ABC system make FMS investment projects more attractive.

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