TIME BASED COSTING FOR LEADTIME MANAGEMENT IN MULTI-PRODUCT LINES

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ABSTRACT

Lead time shortening activities are important for manufacturing firms. However, it is difficult to evaluate the effects of such activities on cost reduction by the traditional costing methods. To solve this problem, a time based costing method is proposed. In addition, capital expenses are added to the cost of a product because usually the equipment investment costs of this kind of manufacturing firms are relatively high. By using the proposal, the cost of each production process of a product can be evaluated with a high accuracy. At the same time, the effect on reducing cost by lead time shortening activities can be evaluated as well.

Keywords: Time based costing, equipment depreciation, lead time reduction.

Introduction

Lead time shortening activities are important for the manufacturing firms whose equipments investment costs are high. This is because high equipments investment costs means high machine depreciation expense. The longer the lead time of a product is, the higher the cost will be. Special examples include the firms of semiconductors and LCD panels.
By time monitoring, the time being spent in each workstation of a product can be clarified, so that the workstation whose lead time is the longest can be focused on. However, since the relationship between lead time and product cost was not clarified, effects on cost reduction by lead time shortening activities were hard to evaluate.

Traditional costing methods usually focus on the input (e.g., material, labor and overhead expenses, etc.) and the output (e.g., volume of each product) of the relevant period to calculate a product's cost.
The direct expenses (e.g., materials, resource expenses, etc.) can be simply allocated to a specific product by considering its material requirement and processing time of resources. In addition, the indirect expenses (e.g., equipment downtime expense, financing costs of equipment purchase, etc.) of the whole shop are collected and then allocated to each kind of product by only taking their quantities [1] into consideration. Since there is also a large number of work in-process (WIP) at each line, the accuracy of the traditional indirect expense allocation method is low. This method was widely used by most single-product lines in which the ratio of direct expenses is relatively high.
However, production type is changing from single-product with large lot size to multiple-product with small lot size. Moreover, the radio of indirect expense has been increased largely. By using the traditional costing method, the difference in cost among product types cannot be clarified, because the indirect expenses have become the majority of the total costs and were equally allocated to each kind of products. Since operations and equipments required for the products differ largely among product types, the traditional costing approach is not suitable to the current multi-product lines, and new costing methods need to be developed for each product type by considering their different production processes.

In order to calculate a product's cost in a higher accuracy than the traditional accounting system, activity based costing became popular from the early 1990's [2]. Activity of each resource is focused on in this method, so that the indirect cost spent on each product can be calculated clearly. However, the weak point of this method is that the costs of idle resources were ignored. In the target lines, equipments investments are high so that idle time of a machine is undesirable and the loss should be evaluated and added to the cost of a product.

On the other hand, some researchers such as Tanaka [3] and Fujimoto [4] proposed a costing method for manufacturing firms by taking capital expense into consideration. This is because usually a manufacturing firm needs to collect funds from outside in order to buy the necessary materials and equipments. However, their method did not consider the expenses incurred by operations.

In order to solve the problems in multi-product lines, a new costing approach is proposed in this paper.
The first aim of the proposal is to clarify the relationship between lead time and product costs, so that any improvement plans on lead time reducing can be evaluated by the cost measurement.
The second aim the proposal is to increase the accuracy of product costing. To achieve this goal, costing methods for direct and indirect expenses need to be reconsidered.
For direct expense, real processing time, instead of standard processing time, is proposed to be used. In the target multi-product lines, necessary operations for completing a product varies among products and a portion of the operations are processed by operators. This means processing time differs among operators according to their different work experiences. The traditional costing method can use the standard time because there were only lines of single-model with a large lot size, and each operator only need to process a

limited set of operations so that they can process the operations in standard time limitations. However, in the target lines, both the product mix and the operators change frequently, in which only a few operators remain who have enough work experiences and can process operations in standard time limitations. Therefore, in order to increase the costing accuracy, this paper uses real processing time at each workstation to calculate a product's direct expense.

For the indirect expense, its weight increase largely in the target lines. Also, this expense is traditionally allocated to products only considering the quantity of each product. Thus, the difference in cost among products trends to be difficult to be distinguished. However, in the multi-product lines, the cost difference does need to be clarified. Therefore, this paper propose to evaluate some items of the traditional indirect expenses as direct expenses so that expenses spent on each product can be distinguished.

As a summary, the details of the idea are 1) time loss (resources' idle time) is evaluated and counted to be direct expense, 2) the expenses spent on changeover and maintenance, which were indirect expenses, are counted and allocated to the relative products.

Therefore, the proposal contains the following three novel characteristics:

(1) It is a time based costing method for a product. Lead time of each product is focused on, and cost of each time interval is accumulated. Thus, cost can be even allocated to a work-in-process;
(2) cost for machine idle time can be calculated and allocated to a relative product as a direct expense;
(3) capital expenses are added to the cost of each product as a direct expense.

Since a set of processes is required for completing a product, this paper focuses on how to calculate the cost of a product at each process. For simplify, each process is supposed to be conducted by only one machine in one workstation with the support of one operator.

To accomplish a product, a set of processes are required (e.g., as shown in Figure 1). Depending on the capability of machines, components of products will be processed at a workstation by single unit (e.g., in Figure 1, Process b) or, batch unit (e.g., in Figure 1, Process a, c).

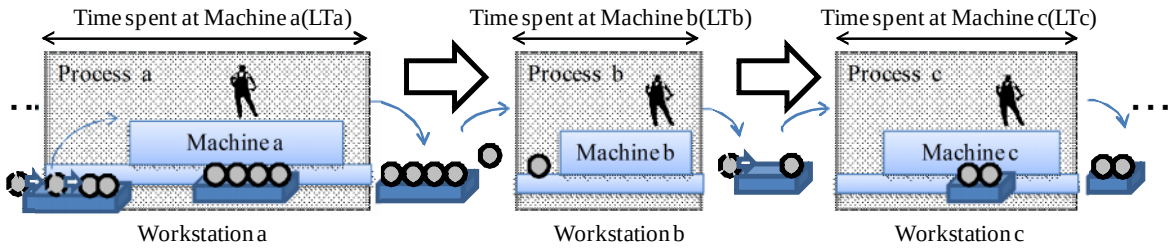

Figure1. Processes required for accomplishing a product

Necessary costing items for lead time management in a workstation

Besides material expenses, there are two types of costs that occur at a workstation. One is resource costs, which includes labor cost and cost related to equipments at that station. The other cost is capital cost.

Resource costs occur when 1) a product is being processed and 2) set up (set off) or maintenance tasks are conducted at that workstation.

Capital cost of a product in a workstation depends on the time that the product occupies the workstation.

By using the idea of capital expense, waiting time of a product (from the viewpoint of a machine, idle time) in a workstation can be evaluated with the cost measurement.

Therefore, this paper proposes to evaluate the cost of producing a product with both the consideration of lead time and capital expense.

In the following sections, firstly, lead time is split into detailed time interval which includes processing time, etc. Then, costing for each kind of time interval is separately calculated and accumulated.

Since huge equipment investments and large operating capital are needed in the target lines, for each kind of time interval, a capital expense is appended. Finally, experimental evaluations of the proposal are conducted.

Breakdown of lead time

To accomplish a product in the multiple product lines, a product (strictly, a work piece or work-in-progress) will be processed by a set of sequential workstations.

In order to clarify the details of lead time at each workstation, necessary operations for a work-piece are focused on. Considering the purpose of an operation, the following items can be listed up:

(i) Set up: set a work piece (or a set of work pieces) to a machine or a work space so that the machine or the allocated operator can process it;
(ii) Processing: a process to change a work piece's sharp, value, or characters;
(iii) Set off: remove the processed work piece from a machine or the work place so that other work pieces

can be processed there;

(iv) Transportation: transport the work piece (or a set of work pieces) to the next workstation;

(v) Prepare for transportation: prepare the necessary materials from the warehouse, or set the work piece(s) to a vehicle.

In the experiments, 106 case studies on manufacturing firms are investigated, and 84 operation examples are confirmed. Table 1 shows the result of the investigation.

Table 1. Confirmation on operation types

Operation Type	Number of examples	Examples
i	32	Set up the work piece to the lathe
ii	24	Cutting, turning, milling, etc.
iii	17	Set off the work piece from the milling machine
iv	9	Transport the work pieces by vehicle from one workstation to the next one
v	2	Prepare the materials for the line

Referring Table 1 and considering the time loss (idle time) which may occur in a workstation, lead time of a product at a workstation consists of processing time, set up (set off) time, waiting time and transportation time.

Before starting (or after finishing) an operation, the work piece of a product is set up to (or set off from) the machine by an operator. The main operation is executed by the equipment (machine) there.

A work piece has to wait for its turn since multi products are processed in the same machine. Also, it has to wait if the machine is broken down or under maintenance.

In addition, since work pieces are transported between the adjacent workstations, transportation time occurs among workstations.

Thus, in this paper, lead time of a product in a workstation can be divided as follows (Figure 2):

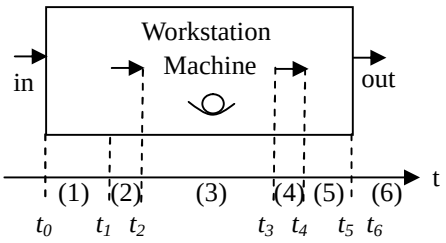

Figure2. Illustration of lead time in a workstation

(1) Time waiting for process (waiting time),
(2) Setup time,
(3) Processing time,
(4) Set off time,
(5) Time waiting for transportation or changeover etc. (waiting time), and
(6) Transportation time.

Cost of processing

A product is processed by a machine at each workstation in the target lines. Here, the equipment depreciation expense is counted as the cost for the period of processing. Therefore, processing cost $Cpro_i$ at workstation i can be calculated by Equation (1), where DE_i is the unit equipment depreciation expense (per hour) of the machine and opt_i is the processing time required in workstation i.

$$Cpro_i = DE_i * opt_i \qquad (1)$$

Cost of set up (set off)

Set up and set off are conducted manually. Considering machine is occupied during this period, both labor cost and equipment depreciation expense are counted.

$$Csetup_i = (LE_i + DE_i) * upt_i \qquad (2)$$

$$Csetoff_i = (LE_i + DE_i) * offt_i \qquad (3)$$

$Csetup_i$, $Csetoff_i$ and LE_i express set up, set off cost and unit labor cost at workstation i, respectively. upt_i and $offt_i$ express the time required for set up and set off at that workstation, respectively.

Cost of waiting

Waiting time occurs when a work piece of a product is transported to a workstation but other product's work is still under processing at that machine. It also happens when the product has been processed and is waiting for transportation resource's arrival, or when the machine is under maintenance or broken down.

By using the traditional costing methods, cost loss of this time period cannot be allocated to a specific product. However, from the viewpoint of lead time management, this time loss is large and its impact on product cost does need to be taken into consideration.

To solve this problem, for the waiting time after maintenance, this paper proposes to re-evaluate depreciation expense of the machine. Total cost spent on maintenance Cm_i is calculated which includes labor or outsourcing expenses. Then, this expense is allocated to the machine for the remaining depreciation period m by Equation (4) as illustrated in Figure 3.

$$DE'_i = DE_i + Cm_i / m \qquad (4)$$

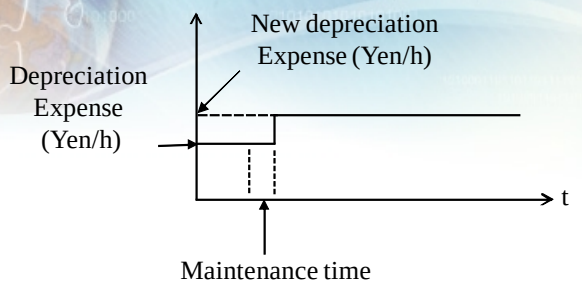

Figure3. Depreciation expense re-evaluation

Therefore, cost of waiting time spent in a workstation $Cwait_i$ can be calculated by Equation (5). Note that waiting time needs to be divided by considering the maintenance period because DE_i will be re-evaluated if the maintenance is conducted. Therefore wt_i and wt'_i are used to express the waiting time spent in workstation i before and after maintenance.

$$Cwait_i = DE_i * wt_i + DE'_i * wt'_i \qquad (5)$$

Cost of transportation

Transportations among workstations are conducted by workers with the transportation equipments. Since transportation equipments are relatively cheap, cost of transportation of a product from workstation to the next one ($Ctrans_i$) is calculated by only considering its labor cost, as concluded by Equation (6). Here, $transt_i$ is the transportation time from workstation i to the next one.

$$Ctrans_i = LE_i * transt_i \qquad (6)$$

Additional cost for machine downtime and capital costs

Costing of each kind of time interval for a product in a workstation has been described above. However, machine downtime also occurs when there are no work pieces at that workstation. This kind of machine downtime implies work load of each workstation of a line is not balanced, or, product switch is not smoothly conducted. By using the traditional costing method, equipment depreciation expenses during this time period cannot be directly allocated to any product. To solve this problem, a cost allocation method is proposed for evaluating this kind of loss.

Whenever machine downtime occurs, WIP of each product in the line during that period will be counted. Equipment depreciation expenses during that period $C_{downtime}$ are averagely allocated to those products.

For example, in Figure 4, suppose the line is consisted of 3 processes. Since Machine b is not running, the equipment depreciation expense during the idle time will be allocated the 10 work pieces which remain in the line during that period.

Figure 4. Target work pieces of the additional cost allocation

On the other hand, capital costs are added to each type of time interval. The details will be described in the next section.

Total cost of a product

In summary, the total cost of a product is calculated by considering its lead time, capital expense at each workstation, and machine downtime losses. Figure 5 shows the image of its cost accumulation in a workstation.

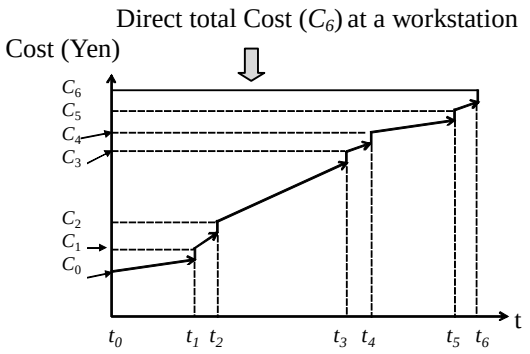

Figure 5. Cost accumulation at a workstation

At time point t_0, only cost of material C_0 is counted. Then, at time point t_1, since the work piece has waited for its process turn, cost of waiting $Cwait'_i$ from time point t_0 to t_1, and the capital expense for C_0 during this time period is added by Equation (7). Here, r is the unit interest rate of liability.

$$C_1 = C_0 + Cwait'_i + C_0 * (t_1 - t_0) * r \qquad (7)$$

In the same way, cost at time point t_2, t_3, t_4, t_5 and t_6 can be calculated by Equation (8) to (12), respectively. Here, $Cwait''_i$ is the waiting cost time from t_4 to t_5.

$$C_2 = C_1 + Csetup_i + C_1 * (t_2 - t_1) * r \qquad (8)$$

$$C_3 = C_2 + Cpro_i + C_2 * (t_3 - t_2) * r \qquad (9)$$

$$C_4 = C_3 + Csetoff_i + C_3 * (t_4 - t_3) * r \qquad (10)$$

$$C_5 = C_4 + Cwait''_i + C_4 * (t_5 - t_4) * r \qquad (11)$$

$$C_6 = C_5 + Ctrans_i + C_5 * (t_6 - t_5) * r \qquad (12)$$

Finally, the total cost of a product can be calculated by adding its cost at each workstation and the cost of machine downtime (if it occurs).

Preparation for the evaluation

The costing method is considered to be used in those lines where main tasks are automatically processed by machines expect set up (set off) tasks. As a precondition, data monitoring of a machine need to be executed in those lines, so that each kind of time interval can be mastered.
With the cooperation of a motor production firm, a line is investigated, in which iron core motor is produced. Here, the following four processes (Figure 6.) are focused on, in which lead time is expected to be shortened.

Process I : Iron core pressing
Process II : Shaft pressing
Process III : Insulation coating
Process IV : Commutator pressing

The other preconditions of the target line are:
(i) There are 3 product types (A, B, C) in the line,
(ii) lot size of each product type are 10,
(iii) products are produced in A, B, C cycle, and
(iv) the line can produce 600 products a day.

Processing time of each product at each workstation, set up (set off), changeover time, and transportation time are set in advance. All the time are considered to follow a normal distribution.
Also maintenance interval is set in advance. Machine break down occurs in a random and unexpected way. Time spent on this kind of repair is also set with a normal distribution.

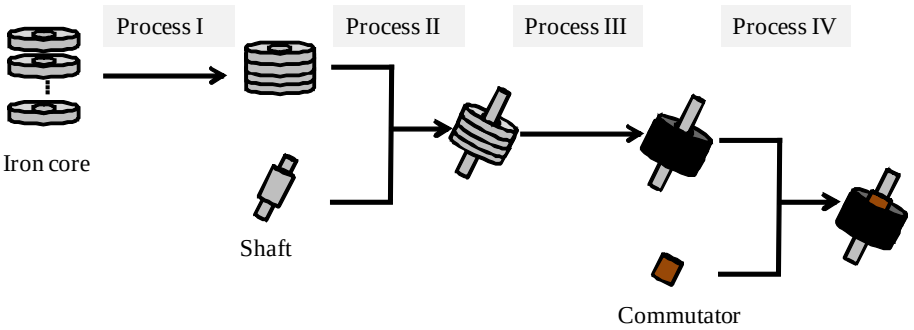

Figure 6. Target processes of an iron core motor line

Test data using in the numerical experiments are created by referring the investigation result of the motor line and some technical manufacturing reports and patents.

In the traditional costing method [1], the equipment depreciation expenses and labor costs are counted as the direct expenses of a product considering how long the equipment and operator has been occupied by that product. Besides, the material expense of producing that product is also counted as the direct expense. Other expenses are collected together and equally allocated to all the products that have been produced during that period as the indirect expenses, which include capital costs, equipment depreciation expenses during machine down time.

Effect on product cost calculation

In the numerical experiments, each product type is supposed to be produced 200 units a day. Here, the average cost of each product type by using the proposed time based costing method is compared with the cost obtained by the traditional method.

Taking the cost of product A as the reference, Figure 7 shows the cost ratio of each product type. It is clarified that there is almost no difference in both indirect and direct expenses among the three product types by using the traditional costing method.

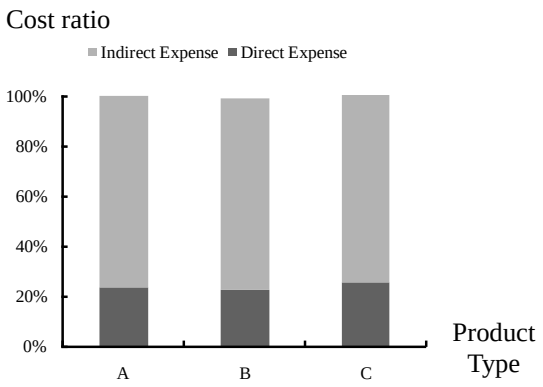

Figure 7. Product cost ratio by using the traditional costing method

However, by using the proposed costing method, the differences in cost among product types become clear (Figure 8). In this example, total cost of product A is clarified to be the largest one. Therefore, product pricing can be set with high accuracy by using the proposal.
Moreover, since direct cost of product A is clarified to be the largest one among the three product types, it is easy to choose the target product for cost reduction by the proposal comparing with the traditional costing method.

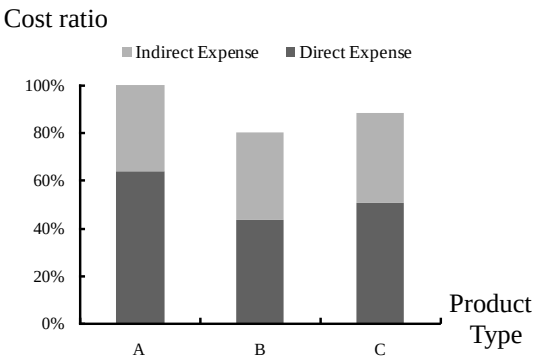

Figure 8. Product cost ratio by using the traditional costing method

Effect on lead time and cost reduction

Lead time shortening is considered as one of the improvement approaches for cost reduction. In order to shorten lead time of a product, usually, lead time of each process is investigated and the process with the longest lead time will be set as the target for improvement.
However, as it is mentioned in the Introduction section, since the relationship between lead time and cost is not clarified, the traditional approach is not effective on reducing cost.

For example, Figure 9 shows one test result of both lead time and cost for the target four processes of product A. Here, average lead time and cost of the 200 products is used for comparison.

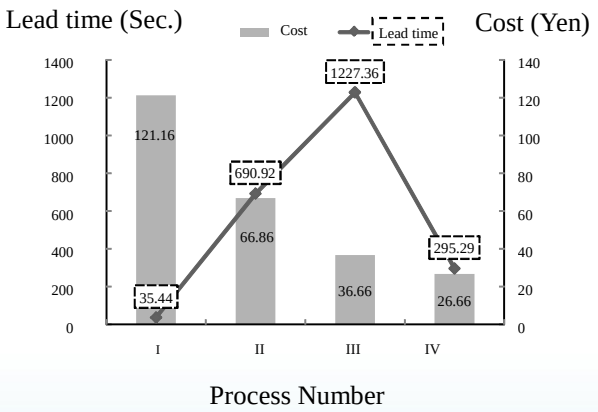

Figure 9. Lead time and cost of each process

Traditionally, Process III will be focused on for improvement since its lead time is the longest.
However, by using the proposal, Process I is set as the target since its cost is the highest.

Thus, two improvement activities can be considered. One is to reduce lead time of Process III by shortening 20 Sec. of its transportation time. The other is to reduce 20 Sec. of processing time in Process I. Here, for simplify, the costs for improvement at each process are supposed to be equal.

Figure 10 and Table 2 show the results of the improvements. The number in the parentheses of Figure 9 shows the workstation number in where lead time reduction activity is conducted.

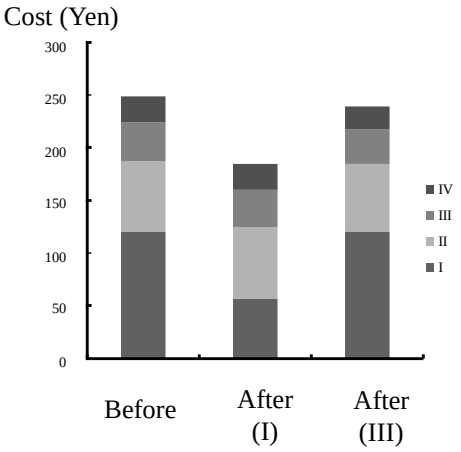

Figure 10. Effects on cost reduction by different improvement activities

Table 2. Improvement rate (%)

Evaluation Item \ Workstation No.	I	III
Cost	25.43	3.85

It is obvious that the proposal can reduce more product cost compared with the traditional method.

Conclusion

A time based costing method for multiple product lines is proposed. By using the proposed approach, cost of each process of a product can be evaluated, so that difference in cost among products can be clarified.
Moreover, the relationship between lead time and cost is also clarified in the present paper. By using the proposal, lead time improvement can be conducted efficiently to reduce a product's cost.

As future directions, more investigations of the target industry can be conducted in order to verify the effects of the proposal in those firms.

REFERENCES

[1]. Sato, M., *Standard Cost Accounting (in Japanese)*, Chuokeizai-sha. Inc., 1997.

[2]. Cooper. R. and Kaplan S. "Profit Priorities from Activity-based Costing", *HARVARD BUSINESS REVIEW*, 1991, May-June, 130-135.

[3]. Tanaka, M. "A study on profitability evaluation considering with the time axis", *IE Review*, 2004, 45(1), 85-92.

[4]. Fujimoto, T. "Cost management from the viewpoint of manufacturing", MMRC Discussion Paper, *Manufacturing Management Research Center of Tokyo University*, 2006, 93, 1-12.