34. Cost Prediction System Using Activity-Based Model for Machine Tool Operation

Hirohisa Narita[1], Lian-yi Chen[2] and Hideo Fujimoto[2]
1 Tsukuri Colloge, Graduate School of Engineering, Nagoya Institute of Technology, Japan
Email: narita@vier.mech.nitech.ac.jp
2 Omohi Colloge, Graduate School of Engineering, Nagoya Institute of Technology, Japan
Email: {chen, fujimoto}@vier.mech.nitech.ac.jp

Production cost is one of the most important factors for manufacturing. The production cost associated with each machine tool is calculated from total cost of factory in general. The operation status of machine tools, however, is different, so accurate production cost for each product can't be calculated. Hence, accounting method of production cost for machine tool operation is proposed using the concept of Activity-Based Costing and is embedded to virtual machining simulator for the cost prediction.

1. INTRODUCTION

Production cost is one of the most important factors to decide the manufacturing process and manufacturing strategies. However, lots of machine tools are installed for production in recent factory and it is difficult to estimate and recognize accurate production cost due to machining operation. That is to say each operation status of machine tools is different, so conventional cost accounting method can not allocate accurate overhead costs and plant expenses to each product as production cost. Hence, the accounting method of production cost is proposed and is embedded to virtual machining simulator, which was developed to predict machining operation, for the cost prediction. So, the cost prediction system developed in this research can realize the automatic calculation of production cost from NC program generated by CAM.

Many research related to production cost prediction has been already carried out (e.g. Ohashi et. al., 2000). But, the difference of cutting conditions like depth of cuts, tool path pattern, feed rate, spindle speed can not be evaluated, so the calculated cost is not correct and this kind of system can not be used as general-purpose evaluation system. In this research, the cost accounting method is proposed using activity-based costing (ABC) (Brimson, J. A., 1997) concept. So far, some researches are carried out to account production cost using ABC concept (e.g. Fujishima, et. al. 2002, Sashio, et. al. 2004) and good results are achieved.

Hence, the cost prediction system which can solve conventional problems is developed based on the accounting method proposed and the feasibility of cost prediction system is shown through case studies in this paper.

2. OVERVIEW OF A PROPOSED SYSTEM

Figure 1 shows an overview of proposed system in this research. This consists of Estimator, Database and Analysis blocks. This system can evaluate NC programs generated by CAM. Here, the electric consumption of machine tool components, coolant quantity, lubricant oil quantity, cutting tool status and metal chip are cost factors in this research. Other factors in the figure mean the evaluation factors which are input by users according to needs like electric consumption of light, air conditioning, AGV's transportation, etc. and are ignored in this paper.

The analysis block can evaluate motions and activities related to machine tool and machining operation. The database block also consists of cost database and resource database. The cost database stores the production and disposal cost of each evaluation factors and the resource database stores machine tool specification data, cutting tool parameter, etc. for the estimation of machining process.

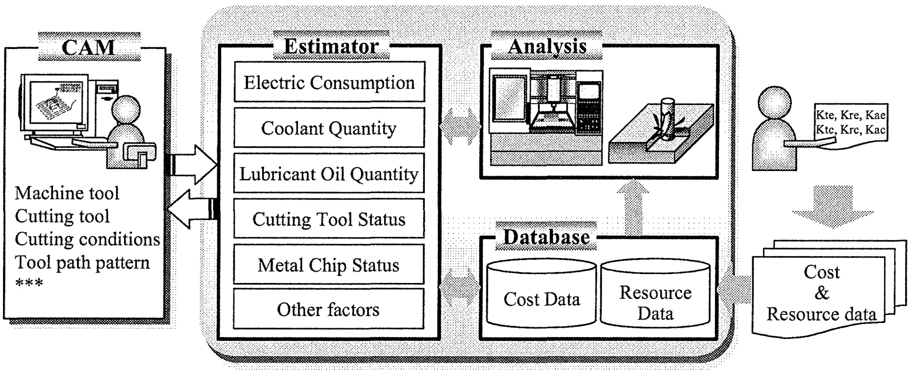

Figure 1. Prediction system of production cost for machining operation

3. CALCULATION METHOD OF PRODUCTION COST

Activity-based costing (ABC) concept is used for the calculation of production cost. Accounting method based on ABC can calculate and allocate production cost to each activity. ABC model is shown in Figure Figure 2. All product costs can be classified to the activities used to manufacture them. Using this method, the system can identify the product cost factors which has direct implications on product cost.

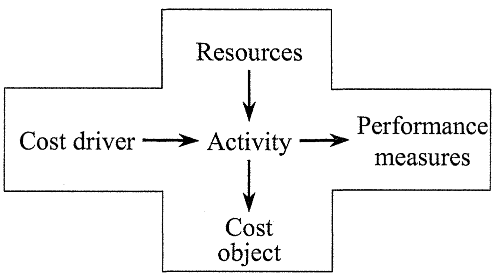

Figure 2. Activity-based model

In this research, cost driver corresponds to machining time, mean time of coolant update, etc., resource corresponds to work piece and cutting tool, cost object corresponds to product and performance measures correspond to analyzed results.

Total cost is calculated by the following equation. In this research, JPY (Japanese Yen) is used as currency.

$$Pc = Ec + Cc + LOc + \sum_{i \to \mathrm{N}} \left(Tc_i\right) + CHc + OTc \tag{1}$$

where

Pc: Cost of machining operation [JPY]
Ec: Cost of machine tool electric consumption [JPY]
Cc: Cost of coolant [JPY]
LOc: Cost of lubricant oil [JPY]
Tc: Cost of cutting tool [JPY]
CHc: Cost of metal chip [JPY]
OTc: Cost of other factors [JPY]
N: Number of tool used in an NC program

In this paper, *OTc* isn't described. Calculation algorithms of *Ec*, *Cc*, *LOc*, *Tc* and *CHc* are described in detail as following.

Machine tool electric consumption (Ec)

The cost of electric consumption of machine tool is expressed by equation (2).

$$Ec = Ebc \times MT + ER \times CE \tag{2}$$

where

Ebc: Basic rate of electricity [JPY/s]
MT: Machining time [s]
ER: Electricity bill [JPY/kWh]
CE: Electric consumption [kWh]

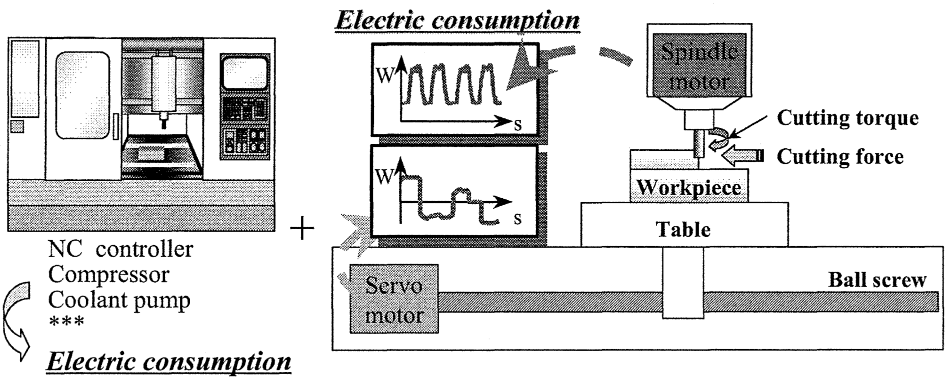

Figure 3. Electric consumption models of machine tools

CE in equation (2) is expressed by equation (3) and correspond to electric consumption of peripheral devices, servo and spindle motors shown in Figure 3. The electric consumption of peripheral devices can be predicted from machining time and each electric power. However, in order to estimate the electric consumption of the servo and spindle motors, cutting force in each axis and cutting torque are required. These values can be estimated by introducing cutting force model (Narita, et.al., 2000). This cutting force model can be applied to other cutting methods like drilling, turning and etc., so electric consumption model of machine tool proposed in this research can evaluate various machining operations.

$$CE = SME + SPE + SCE + CME + CPE + TCE1 + TCE2 + ATCE + MGE + VAE \quad (3)$$

where

SME: Electric consumption of servo motors [kWh]
SPE: Electric consumption of spindle motor [kWh]
SCE: Electric consumption of cooling system of spindle [kWh]
CME: Electric consumption of compressor [kWh]
CPE: Electric consumption of coolant pump [kWh]
TCE1: Electric consumption of lift up chip conveyor [kWh]
TCE2: Electric consumption of chip conveyor in machine tool [kWh]
ATCE: Electric consumption of ATC [kWh]
MGE: Electric consumption of tool magazine motor [kWh]
VAE: Vampire (Standby) energy of machine tool [kWh]

Coolant (*Cc*)

Coolant (water-miscible cutting fluid type) is generally used to enhance machining performance, and circulated in a machine tool by coolant pump until coolant is updated. During the period, some cutting oil is eliminated because of adhesion to metal chip and water escape as vapor, so additional quantity of coolant and water has to be considered. Hence, following equation is adapted to calculate the cost due to coolant.

$$Ce = \frac{CUT}{CL} \times \{(CPc + CDc) \times (CC + AC) + WAc \times (WAQ + AWAQ)\}$$

(4)

where

CUT: Coolant usage time in an NC program [s]
CL: Mean interval of coolant update [s]
CPc: Purchase cost of cutting fluid [JPY/L]
CDc: Disposal cost of cutting fluid [JPY/L]
CC: Initial coolant quantity [L]
AC: Additional quantity of coolant [L]
WAc: Water distribution cost [JPY/L]
WAQ: Initial quantity of water [L]
AWAQ: Additional quantity of water [L]

Lubricant oil (*LOc*)

Lubricant oil is mainly used for spindle and slide way, so two equations are introduced. Here, oil-air lubricant is treated for spindle lubricant. The following equations are adapted to calculate the cost due to lubricant oil. Grease lubricant is not mentioned, but almost same equations can be adapted to calculate the cost.

$$LOc = Sc + Lc \tag{5}$$

where

Sc: Cost per an NC program due to Spindle lubricant oil [JPY]
Lc: Cost per an NC program due to slide way lubricant oil [JPY]

$$Sc = \frac{SRT}{SI} \times SV \times \left(SPc + SDc\right) \tag{6}$$

where

SRT: Spindle runtime in an NC program [s]
SV: Discharge rate of spindle lubricant oil [L]
SI: Mean interval between discharges [s]
SPc: Purchase cost of spindle lubricant oil [JPY/L]
SDc: Disposal cost of spindle lubricant oil [JPY/L]

$$Lc = \frac{LUT}{LI} \times LV \times \left(LPc + LDc\right) \tag{7}$$

where

LUT: Slide way runtime in an NC program [s]

LI: Mean interval between supplies [s]

LV: Lubricant oil quantity supplied to slide way [L]

LPc: Purchase cost of slide way lubricant oil [JPY/L]

LDc: Disposal cost of slide way lubricant oil [JPY/L]

Cutting tool (*Tc*)

Cutting tools are managed from the view point of tool life. So, tool life is compared with machining time to calculate the production cost in one machining. Also, the cutting tools, especially for solid end mill, are made a recovery by re-grinding, so these points are considered to construct cost equation.

$$Tc = \frac{MT}{TL \times \left(RGN + 1\right)} \times \left(\left(TPc + TDc\right) \times TW + RGN \times RGc\right) \tag{8}$$

where

MT: Machining time [s]
TL: Tool life [s]
TPc: Purchase cost of cutting tool [JPY/kg]
TDc: Disposal cost of cutting tool [JPY/kg]
TW: Tool weight [kg]
RGN: Total number of re-grinding
RGc: Cost of re-grinding [JPY]

Metal chip (*CHc*)

Metal chips are recycled to material by electric heating furnace. This materialization process has to be considered. This equation is supposed to consider material kind, but electrical intensity of this kind of electric heating furnace is represent by kWh/t, so equation constructed in this research is calculated from total metal chip weight.

$$CHc = \left(WPV - PV\right) \times MD \times WDc \tag{9}$$

where

WPV: Work piece volume [cm^3]

PV: Product volume [cm^3]

MD: Material density of work piece [kg/cm^3]

WDc: Processing cost of metal chip [JPY/kg]

So far, cutting simulation system called VMSim (Virtual Machining Simulator) has been developed (Narita, et. al., 2000, 2002). Cutting force, cutting torque, machining time and machine tool motion which are the parameters to calculate cost can be predicted from NC program. Hence, prediction system for production cost has been developed by embedding the proposed calculation algorithm to VMSim.

4. CASE STUDIES

In order to show the feasibility of developed system, two case studies are introduced. In these case studies, machine tool is MB-46VA (OKUMA Corp.), cutting tool is carbide square end mill with 12mm diameter, 2 flutes and 30 deg. helical angle and work piece is medium carbon steel (S50C). The cost data are obtained by searching the companies' web site and asking the manufacture's branch offices. Table 1 shows the parameters of machine tool, work piece and cutting tool.

Table 1 Parameters of machine tool, work piece and cutting tool

Initial coolant quantity [L]	8.75
Additional quantity of coolant [L]	4.3
Initial quantity of dilution fluid [L]	166.25
Additional quantity of dilution fluid [L]	81.7
Mean interval between replacements of coolant in pump [Month]	5
Discharge rate of spindle lubricant oil [mL]	0.03
Mean interval between discharges for spindle lubrication [s]	480
Lubricant oil supplied to slide way[mL]	228
Mean interval between supplies [hour]	2000
Tool life [s]	5400
Total number of re-grinding	2
Material density of cutting tool [g/cm^3]	11.9
Material density of work piece [g/cm^3]	7.1

Case study 1:

Conventional prediction system of production cost for machining operation can not compare different machining strategies which manufacture same product shape, so this kind of comparison is shown first. Figure 4. shows the product shape and tool path pattern of two NC programs termed Program 1 and Program 2. Feed rate and spindle speed of each program are summarized in Table 2. These machining operation are also carried out by dry machining.

Analysis results of two NC programs are shown in Figure 5. In the figure, metal chip become profit in Japan, so this indicates minus value. Total production of Program 1 is larger than one of Program 2. So, from the view point of production cost, Program 2 is better than Program 1, though same product is manufactured. This kind of evaluation, which can not be realized by conventional evaluation system, can be achieved by developed system easily. That is to say various machining strategies effectively before real manufacturing.

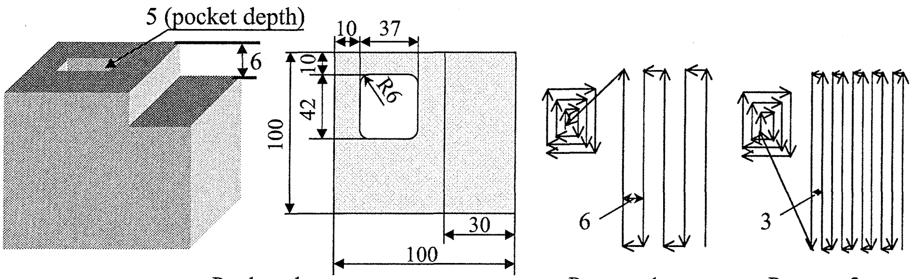

Figure 4. Product shape and tool path pattern of case studies

Table 2. Cutting conditions of two NC programs

	Program 1	Program 2
Spindle speed [rpm]	2500	5000
Feed rate [mm/min]	200	400

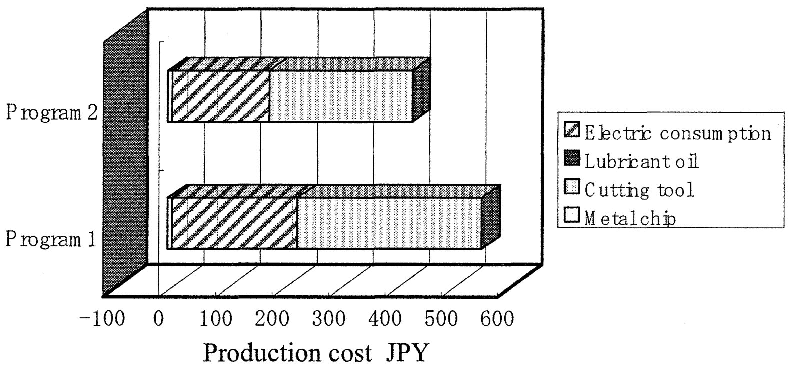

Figure 5: Analyzed production cost of two NC programs

Case study 2:

In order to verify the coolant effect on production cost, Program 1 and Program 2 with coolant usage is evaluated. Water-miscible cutting oil of A1 type (emulsion) is used in this case. Also, it is assumed that cutting tool life is extended to 1.5 times of original one due to coolant effect.

Analysis results are shown in Fig. 6. As shown, the total production costs of both NC programs are reduced from the ones of case study 1 (dry machining). This is the reason why cutting tool cost is reduced by the mitigation of tool wear due to the coolant effect. It is also found that the portions of coolant cost are very small, and the ones of peripheral devices run due to coolant usage like coolant pump, chip conveyer in machine tool is very small, too. Hence, the reduction of cutting tool cost is the most effective to realize the low cost machining in this case study. This kind comparison can be carried out quickly by developed system.

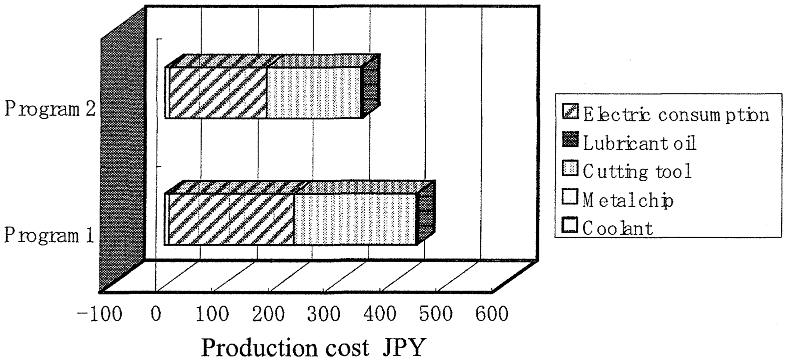

Figure 6. Analyzed production cost of two NC programs with coolant

Here, the environmental burden against global warming is evaluated using equivalent CO_2 emission intensity data (Narita, et. al., 2004). These emission intensities are obtained from environmental report, technical report, web page and industrial table. Environmental burden analysis can be realized that cost data in equations (2)-(9) is basically changed to equivalent CO_2 emission intensity data.

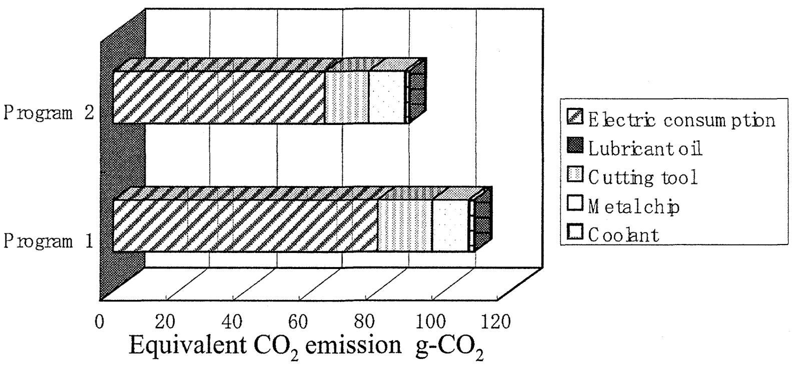

Figure 7. Analyzed equivalent CO_2 emission of two NC programs with coolant

Analyzed results are shown in Figure 7. As shown in the figure, Program 2 is better than Program 1 from the view point of equivalent CO_2 emission. This tendency is same to cost results. From the case study 2, it is found that the reduction of electric consumption of machine tool peripheral device is effective from the view point of equivalent CO_2 emission. In general, it is said that CO_2 emission has the proportional relationship to the cost, but CO_2 emission is not always correlate well with the cost in machining operation from the results of cost and CO_2 emission of electric consumption and cutting tool. Hence, in order to realize the low cost and low environmental burden machining, we have to evaluate them precisely and decide the improvement strategies depending on the situation. Using calculation model proposed in this research, production cost and environmental burden are compared easily before the real machining operation, so developed system will contribute enormously to the future manufacturing system.

5. CONCLUSIONS AND FURTHER WORK

Conclusions are summarized by the followings

- The cost calculation methods for machine tool operation using an activity-based model have been proposed and a cost prediction system has been developed;
- The feasibility of the developed system has been demonstrated through case studies.

Future work is how to take into account indirect labor cost, maintenance cost and fixturing cost. We hope this system will play an important role to contribute the cost down of manufacturing processes and improvement of manufacturing technologies.

Acknowledgments

We would like to express our sincere appreciation to OKUMA Corp. on thoughtful support.

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