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THE USE OF SIMULATION IN ACTIVITY-BASED COSTING FOR FLEXIBLE MANUFACTURING SYSTEMS

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ABSTRACT

A framework to design simulation models is described in order to perform activity-based costing for flexible manufacturing systems before actual manufacturing activities.

For illustrating a procedure to perform activity-based costing, analysis of the random-access type of the flexible manufacturing system (FMS) is performed from both efficient and economic standpoints, by simulating. The flexible manufacturing system considered in this paper consists of NC machine tools (i.e., one NC lathe, one turning center, and two machining centers), one washing machine, the AS/RS, and AGVs. Workparts are machined at the assigned NC machine tool(s) in the predetermined order of operations, and then transferred by AGVs. Set-up operations are performed by the industrial robot located inside the AS/RS.

In this study, a simulation model for a FMS is constructed. Then a procedure for cost accounting is developed for obtaining the unit cost of the products through simulation experiment. It is shown that precise cost accounting can be performed before actual manufacturing activities, if kinds of designated products and their production quantities are specified.

1 INTRODUCTION

Accurate determination of cost components for the operation of a factory can play an important role in that factory's success. However, current methods of accounting in use in most factories do not always describe or allocate costs accurately. One major reason is variance of cost between predicted and actual figures. In this study the problem mentioned above will be resolved by performing simulation experiments. Including costs as well as times on every operation provides an effective implementation of cost modeling methodologies on the factory floor.

Cost analysis and cost accounting before performing actual operations are performed for a random-access type of flexible manufacturing system. A procedure for cost accounting is developed for obtaining the manufacturing costs by utilizing simulation results. In addition, it is concluded that cost reduction could be achieved by increasing operation time per day, by analyzing the contents of the manufacturing costs.

2 THE FLEXIBLE MANUFACTURING SYSTEM

The flexible manufacturing system (FMS) completely controls both material and information flows in an on-line, real-time mode, and is particularly suitable for a job shop concerned with production of versatile items (Hitomi 1979). The use of machining centers with adaptive control devices will increase flexibility of the system and machine utilization.

The flexible manufacturing system considered in this paper comprises four NC machine tools (one NC lathe, one turning center, two types of machining centers), one washing machine, two AGVs, one AS/RS with an industrial robot, and so forth (Takakuwa 1995). Workparts are transferred by one of the AGVs, and they are set up by one industrial robot inside an AS/RS. Furthermore, each workpart is loaded and unloaded by each industrial robot associated with each machine tool, before and after machining. (The animation layout for this system is shown in Figure 1 (b).)

Operation sequences and the associated processing times for the selected workparts are summarized in Table 1. As an example, let us trace the movement of product 1 shown in Table 1. The operation sequence is a NC lathe, a turning center, a vertical type of machining center, a washing machine, a horizontal type of machining center, and again a washing machine. Every workpart first comes out from the AS/RS and awaits an available AGVs. Then it is moved to the NC station (i.e., the first station). After machining at the station, it is moved to the turning center (i.e., the second station). Before machining at each of the two machining centers, each workpart should be set up for machining by the industrial robot inside the AS/RS.

Table 1: Operations Sequence and Processing Time

Part type	NC lathe	Turning center	V. machining center	H. machining center	Washing machine
Product 1	1 116.4	2 306	3 604.7	5 793.8	4,6 180(x2)
Product 2		1 255.6	2 510		3 180
Product 3	1 386.4				
Product 4	1 291.6				
Product 5		1 666.6			
Product 6		1 605.4			
Product 7			1 791.4	3 853.2	2,4 180(x2)
Product 8			1 796.2		2 180
Product 9				1 864	2 180

[Upper: the sequence of operations; Lower: the processing time(sec.)]

3 COST ACCOUNTING WITH SIMULATION

3.1 Manufacturing Costs

Manufacturing costs comprise direct costs and indirect costs in production (the following items are added for the model of the flexible manufacturing system in this study).

(1) Direct cost
- direct materials: material cost
- direct labor: N/A
- direct expenses: N/A

(2) Indirect cost
- indirect materials:
  - cost of cutting oil
  - cost of cutting edges
- indirect labor: wages
- indirect expenses:
  - depreciation (machine tools/equipment)
  - electricity charge
  - taxation

3.2 Cost Variance

Regarding the cost variance, there are at least six sources of variance: (1) inappropriate standard, (2) mismeasurement of actual results, (3) implementation breakdown, (4) parameter prediction error, (5) inappropriate decision model, and (6) random variation (Horngern and Foster 1987). Each source may call for different corrective actions, and all of these corrective actions are costly. Especially, regarding the parameter prediction error, planning decisions are based on predictions, such as future costs, future selling prices, and future demand. In many cases, there will be a difference between the realized value and the predicted value of the cost and so forth. Reducing this source of variance requires development of a better prediction model. In this paper, a simulation model is adopted as such a prediction model.

3.3 Simulation-Based Cost Accounting

Now, current cost-accounting methods are unable to account for many of the costs incurred in production because of the difficulty in tracking the parts through the entire production operation. It is almost impossible to estimate accurate performance of the production operation without simulation. Simulation provides the ideal tool for cost estimating since it provides a complete summary of production activity.

One of the most common means of allocating costs to products has been based on proportioning them on direct labor costs, even though in modern highly mechanized systems direct labor costs may only be a small fraction of total cost (Kaplan 1984). A simulation can also be used as a basis for defining and calculating these costs as the product moves through the system. These costs may be associated with stations in the simulation model through which the product passes and may include the contribution to cost of added materials, of set-up transactions, of frequency in handling, and other detailed considerations that realistically add to the cost of manufacturing (Zuk et al. 1990).

Production/cost information can be obtained through simulation as follows.

(1) Information on machining
- machining time (for each machine)
- number of finished parts
- processing time
- tool-replacement time
- etc.

(2) Information on materials handling
- travel time
- work-in-process inventory
- etc.

In this study, the simulation is performed by SIMAN (Pegden et al. 1994); however, the basic idea of this procedure can be applied to other simulation languages.

Another important issue is where the determination of costs should occur when modeling: during the simulation or after the simulation. Cost determination should occur after simulation, because the “unallocatable” costs are not as well known during the simulation as they are after the simulation.

3.4 Activity-Based Costing

Regarding the hierarchy of factory operating expenses, four activities are separated in activity-based costing, that is, unit-level activities, batch-level activities, product-sustaining activities, and facility-sustaining activities (Cooper and Kaplan 1991). Firstly, expenses for unit-level activities consist of direct labor, materials, machine costs, energy, and so on. Secondly, expenses for batch-level activities consist of setups, material movements, purchase orders, inspection, and so on. Thirdly, product-sustaining activities consist of process engineering, product specifications, engineering change notices, product enhancement, and so on. Finally, facility-sustaining activities consist of plant management, maintenance of the building and grounds, heating and lighting , and so on. Unit-level activities and batch-level activities could be examined through simulation from among those activities. Therefore, these issues are treated solely for analysis in this study.

The procedure of applying fixed costs to products through a cost markup percentage, based on some reasonable measure of activity in a department (machine-hours in fabrication, labor-hours in assembly), had its origins in the financial accounting requirement to allocate all production costs to items produced. This system works well at the aggregate level of financial statements – to obtain values for inventory and cost of sales – and is generally inexpensive to operate. However, the system can produce enormous errors in attributing the consumption of production resources to individual products (Kaplan and Atkinson 1989).

In an activity-based system, the cost of a product is the sum of the cost of all activities required to manufacture and deliver the product. The allocation bases used by activity-based cost systems are termed *cost drivers*. A variety of cost drivers can be used to trace volume-unrelated costs, including:

- Setup hours.
- Number of setups.
- Material handling hours.
- Number of times handled.
- Ordering hours.
- Number of times ordered.
- Part number administration hours.
- Number of part numbers maintained.

Managing costs across the firm means managing the costs incurred before the product is manufactured (upstream costs, i.e., research and development, and product design, and so on), while the product is manufactured (manufacturing costs), and after the product is manufactured (downstream costs, i.e., marketing, distribution, customer service, and so on). Total manufacturing cost is the sum of the cost of materials, labor, and applied overhead. If manufacturing overhead were a negligible portion of total product cost, misapplication of manufacturing overhead would not be a concern. However, in a business environment characterized by high technology manufacturing, overhead cost is a large percentage of total manufacturing cost. While overhead as a percentage of total manufacturing costs has steadily increased, the percentage of direct labor content has decreased (Ruhl and Bailey, 1994).

4 SOME IMPORTANT ASPECTS OF EFFICIENCY AND COST ANALYSIS

Before performing cost analysis it should be stressed that there exist some important aspects of efficiency and cost analysis. In this section, issues on "product-mix/ machine loading" and "scheduling effect" are selected especially to be examined, by performing simulation experiments.

4.1 Product-Mix and Machine Loading

Since available resources for production, such as machines and labor, are limited for each individual manufacturing firm, it is desirable to effectively allocate and utilize those production resources which determine the optimal kinds and quantities of products to manufacture.

Now, suppose that we want to produce some kinds of products from among nine products shown in Table 1 with the production resources in one shift of operation, i.e., eight hours. To solve this product-mix and requirements problem, the following linear programming model is obtained:

Maximize $20.1\,x_1 + 19.8\,x_2 + 6.70\,x_3 + 6.70\,x_4 + 6.50\,x_5 + 6.50\,x_6 + 1.91\,x_7 + 8.60\,x_8 + 15.8\,x_9$

subject to

$116.4\,x_1 + 386.4\,x_3 + 291.6\,x_4 \quad 28{,}800$

$306\,x_1 + 255.6\,x_2 + 666.6\,x_5 + 605.4\,x_6 \quad 28{,}800$

$604.7\,x_1 + 510\,x_2 + 791.4\,x_7 + 796.2\,x_8 \quad 28{,}800$

$793.8\,x_1 + 853.2\,x_7 + 864\,x_9 \quad 28{,}800$

$360\,x_1 + 180\,x_2 + 360\,x_7 + 180\,x_8 + 180\,x_9 \quad 28{,}800$

$x_1 - x_2 = 0$

$\boldsymbol{x} \quad \mathbf{0}$: integer

The objective function is the total profit gained, and 28,800 time units (seconds) are available for machine resources. In addition, the last constraint means that the numbers of product 1 and product 2 should be same for production to put them together.

The optimal solution to the above-listed problem is obtained as follows: $x_1^* = 25$, $x_2^*=25$, $x_4^*=88$, $x_6^*=23$, $x_9^*=9$ (pcs.). However, the time needed to produce all these products would be approximately 41,000 to 61,000 seconds, by performing simulation, and it is found to be much more than 28,800 seconds. Hence, all these products cannot be produced definitely within one shift of operation.

4.2 Scheduling Effects

In the dynamic situation, workpieces arrive at the shop randomly over time, so that the shop itself behaves like a network of queues. In this context, scheduling is generally carried out by means of dispatching decisions: at the time a machine becomes free a decision must be made regarding what it should do next. These scheduling decisions are unavoidable in the operation of such a system (Baker 1974). In this section, seven scheduling rules , i.e., LWKR(Least Work Remaining), MWKR (Most Work Remaining), TWORK (Total Work), LTWORK (Least Total Work), FCFS (First Come First Served), SPT (Shortest Processing Time), and FASFS (First Arrival at the Shop First Served) are applied to all queues in the system, when performing simulation.

A list of maximum flow times to process the set of products (i.e., 25 pieces of product 1, 25 pieces of product 2, 88 pieces of product 4, 23 pieces of product 6, and 9 pieces of product 9) obtained in the previous section is summarized in Table 2, adopting each scheduling rule. It is observed that the maximum flow time under the MWKR (Most Work Remaining) rule is the minimum among those under any other scheduling rules in this case. This result demonstrates substantial differences on the maximum flow time by applying the dispatching procedure; it is important to seek out the decision rules that promote good performance.

Table 2: Maximum Flow Time under Major Scheduling Rules

(sec.)

Scheduling rule	Maximum flow time
LWKR (Least Work Remaining)	51,778
MWKR (Most Work Remaining)	41,402
TWORK (Total Work)	51,796
LTWORK (Least Total Work)	41,408
FCFS (First Come First Served)	61,078
SPT (Shortest Processing Time)	48,044
FASFS (First Arrival at the Shop First Served)	61,078

5 SEMI-GENERATIVE PROCEDURE OF ACTIVITY-BASED COSTING WITH SIMULATION

5.1 The Procedure

A semi-generative procedure of activity-based costing with simulation is proposed in this study, especially for the flexible manufacturing system described in section 2. The price (numerical examples) and the service life of each system component of the flexible manufacturing system is summarized in Table 3. Miscellaneous costs such as system controllers are assigned adequately to the corresponding items listed in Table 3. The service life is needed to calculate depreciation for each equipment unit.

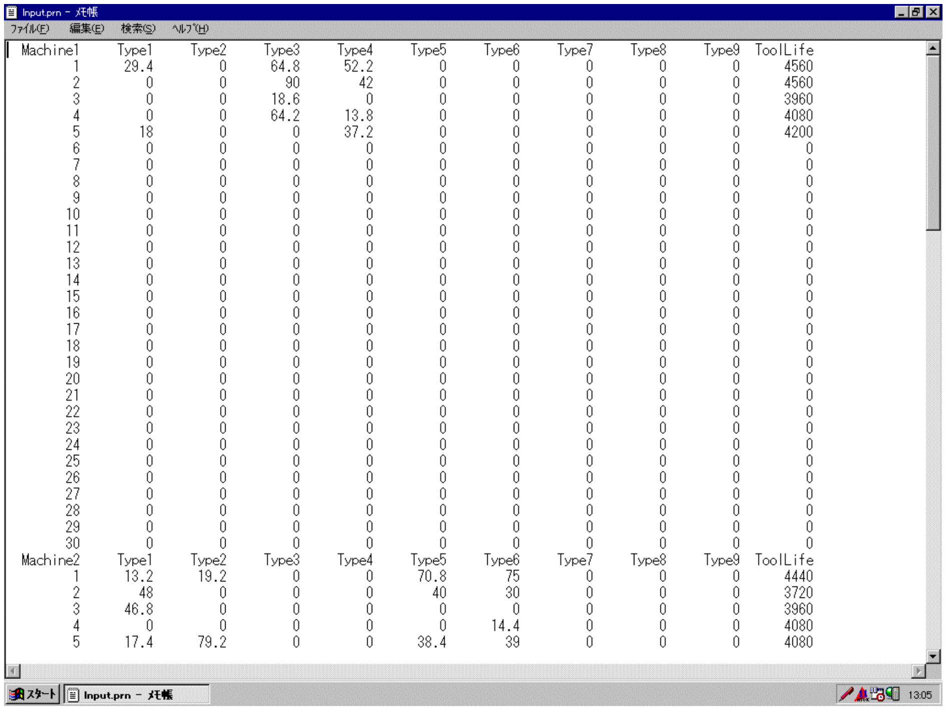
There are two major stages: (1) simulation and (2) activity-based costing in the procedure. The scheme of this procedure is indicated in Figure 1. By using this generative system, activity-based costing would start automatically without inputting any data, immediately after a simulation experiment is finished and the corresponding Excel file is opened. Thus all of the required calculation will be made by the system.

Item	Price ($1,000)	Service life (years)
NC lathe	373.6	10
Turning center	436.7	10
V. Machining center	461.6	10
H. Machining center	501.1	10
Washing machine	175.8	10
AGV system	1,025.6	12
AS/RS	732.5	10
Tool management	293.1	10
Total	4,000.0	-

Table 3: Price and Service Life of the System

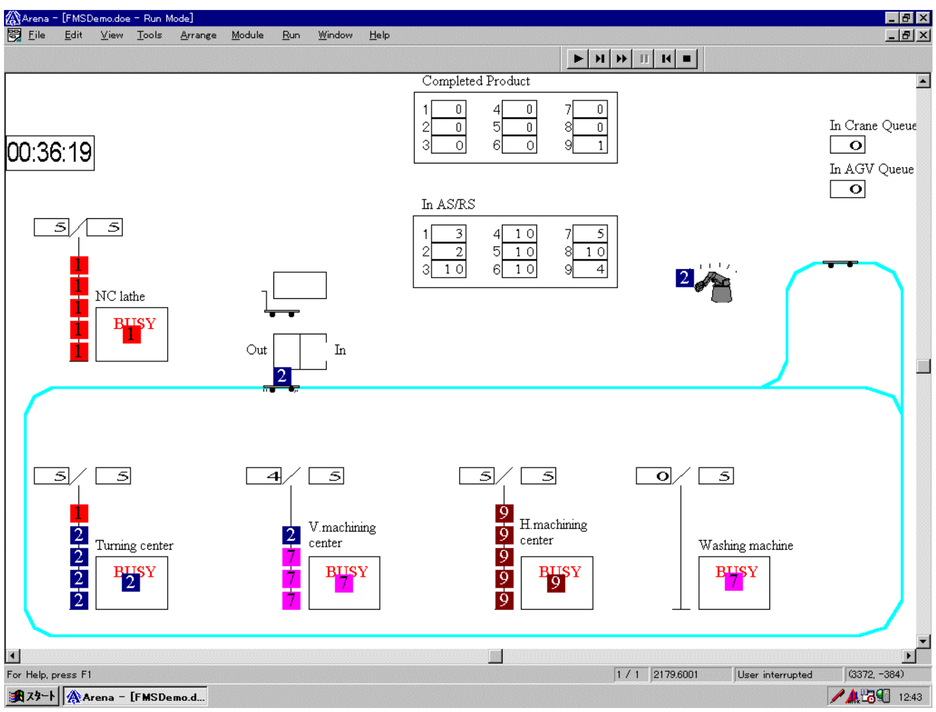
Figure 1 illustrates the general procedure to execute simulation experiment with the resultant external files and generate a series of activity-based costing tables in one Excel file. One external file is required to perform simulation in advance, as shown in Figure 1 (a). This file contains all data on the machining time for each specified workpart with each cutting edge at each machine tool. The animation layout for the flexible manufacturing system is shown in Figure 1 (b). The numbers of finished workparts are indicated on the screen as well.

After simulation is performed, one external file will be generated; it contains the summary of machining time with each cutting edge at every machine tool. The external file is shown together with the ARENA summary report in Figure 1 (c). Immediately after the corresponding Excel file is opened, the required data obtained by simulation will be automatically inputted to the file. Four sheets of the Excel file are selected and shown in Figure 1 (d). Then, activity-based costing will be performed, by filling the required cells of a series of Excel sheets sequentially and automatically. Finally, the unit manufacturing cost for each product will be obtained in the final sheet of the Excel file. Thus activity-based costing will be done, by making use of simulation results.



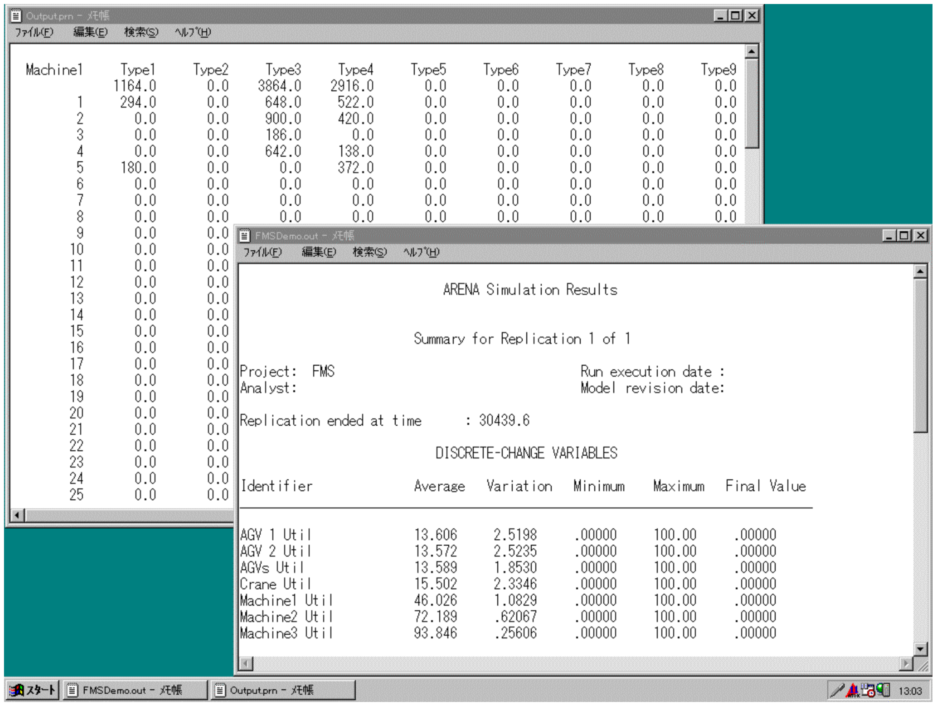
Machine1	Type1	Type2	Type3	Type4	Type5	Type6	Type7	Type8	Type9	ToolLife
1	29.4	0	64.8	52.2	0	0	0	0	0	4560
2	0	0	90	42	0	0	0	0	0	4560
3	0	0	18.6	0	0	0	0	0	0	3960
4	0	0	64.2	13.8	0	0	0	0	0	4080
5	18	0	0	37.2	0	0	0	0	0	4200
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0
Machine2	Type1	Type2	Type3	Type4	Type5	Type6	Type7	Type8	Type9	ToolLife
1	13.2	19.2	0	0	70.8	75	0	0	0	4440
2	48	0	0	0	40	30	0	0	0	3720
3	46.8	0	0	0	0	0	0	0	0	3960
4	0	0	0	0	0	14.4	0	0	0	4080
5	17.4	79.2	0	0	38.4	39	0	0	0	4080

(a) External File (Input)

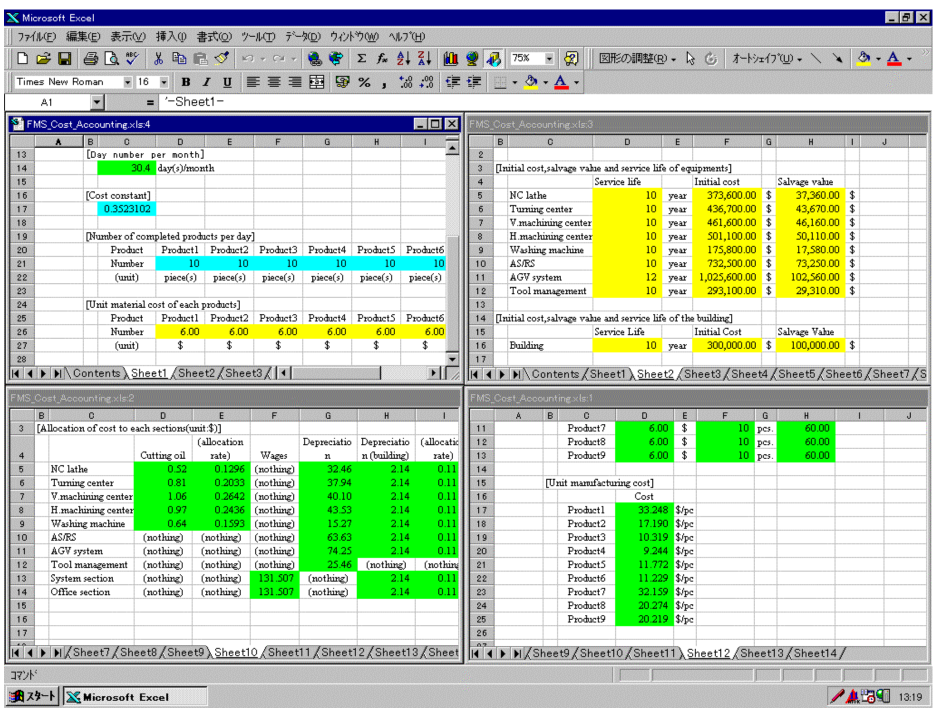


(b) Performing Simulation

Figure 1: A Semi-Generative Procedure of Activity-Based Costing with Simulation (Continued)



(c) Summary Report and External File (Output)



(d) Semi-Genetive Activity-Based Costing System

Figure 1: A Semi-Generative Procedure of Activity-Based Costing with Simulation

5.2 Cost Accounting for Various Types of Products

Table 4 shows the detailed contents of cost accounting to produce the specified numbers of pieces of the five types of products (i.e., product 1: 25 pcs., product 2: 25 pcs., product 4: 88 pcs., product 6: 23 pcs., and product 9: 9 pcs. shown in Table 1 in this case), when applying the SPT scheduling rule on every queue such as the queue for AGVs at the exit of AS/RS. Although there are a lot of subsidiary tables as shown in Figure 1, major results on accounting are summarized in Table 4.

Table 4 comprises two major parts, that is, fixed costs and variable costs. A fixed cost is a cost that remains unchanged in total for a given time period despite wide changes in the related total activity or volume. In this case, depreciation, cutting oil, electricity charge, and so on, are classified into fixed costs. On the other hand, a variable cost is a cost that changes in total in direct proportion to changes in the related total activity or volume. For example, material costs are variable costs. The contents of all cost items are summarized and used for calculating the unit manufacturing costs of products.

The term *Percentage of value added* stands for the relative ratio of value added for each product which is produced through this manufacturing system. In this case, these values are used as the rates for allocating fixed costs (Sakurai 1995). Now, it is assumed that the values of 39, 19, 11, 12, and 19 are assigned in percentage for each product respectively. The unit manufacturing costs of these five types of parts are approximately \$31.93, \$17.27, \$7.69, \$11.16, and \$27.73, respectively, as shown in Table 4. It is found that precise activity-based cost accounting can be performed before actual manufacturing activities. If the more reasonable ratios could be adopted for allocating fixed costs, the values might be substituted by them.

Applying seven scheduling rules described in section 4.2, activity-based costing is performed for each scheduling rule, together with corresponding simulation experiment. The unit manufacturing costs for all products are summarized in Table 5. It is found that the manufacturing cost might vary, depending on the adopted scheduling rule.

6 SUMMARY

A framework of the semi-generative procedure of activity-based costing with simulation is proposed. Activity-based costing analysis of the random-access type of the flexible manufacturing system (FMS) is performed from both efficient and economic standpoints, by performing simulation; and numerical examples are demonstrated, based on an real flexible manufacturing system. In addition, it is shown that precise cost accounting can be performed by utilizing simulation before actual manufacturing activities are performed, if kinds of designated products and their production quantities are specified.

Table 4: Summary of Activity-Based Costing in Applying SPT Rule

Item		NC lathe	Turning center	V.machining center	H.machining center	Washing machine	AS/RS	AGV system	Management	System administration	Total
Cutting oil	(\$)	1.68	1.25	1.20	1.17	0.83	0.00	0.00	0.00	0.00	6.13
Depreciation(equipment)	(\$)	49.78	58.19	61.51	66.77	23.42	97.60	113.88	0.00	39.05	510.21
Depreciation(building)	(\$)	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	29.61
Electricity charge(fixed)	(\$)	4.88	3.62	3.50	3.41	2.40	1.03	0.90	0.13	0.13	20.00
Taxation	(\$)	1.98	2.21	2.21	2.21	0.89	3.97	4.28	0.00	0.00	17.77
Total(fixed cost)	(\$)	61.61	68.57	71.71	76.85	30.83	105.89	122.35	3.42	42.48	583.72
Total(to be allocated)	(\$)	61.61	68.57	71.71	76.85	30.83	105.89	122.35	3.42	42.48	583.72
Wages	(\$)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	131.51	131.51	263.01
Electricity charge(variable)	(\$)	27.37	20.33	19.61	19.10	13.47	5.78	5.05	5.05	5.05	120.81
Total(variable cost)	(\$)	27.37	20.33	19.61	19.10	13.47	5.78	5.05	136.55	136.55	383.82
Total(to be allocated)	(\$)	88.98	88.89	91.32	95.95	44.30	111.67	127.41	139.98	179.03	967.54

Item		Product1	Product2	Product3	Product4	Product5	Product6	Product7	Product8	Product9	Total
Percentage of value added	(%)	39	19	0	11	0	12	0	0	19	100
Total(to be allocated)	(\$)	227.65	110.91	0.00	64.21	0.00	70.05	0.00	0.00	110.91	583.72
Total(variable cost)	(\$)	164.59	71.36	0.00	77.47	0.00	42.03	0.00	0.00	28.36	383.82
Cutting edges	(\$)	256.12	99.60	0.00	7.11	0.00	6.62	0.00	0.00	56.33	425.79
Material cost	(\$)	150.00	150.00	0.00	528.00	0.00	138.00	0.00	0.00	54.00	1020.00
Manufacturing cost	(\$)	798.36	431.87	0.00	676.79	0.00	256.70	0.00	0.00	249.60	2413.33
Quantities	(pcs.)	25	25	0	88	0	23	0	0	9	170
Unit manufacturing cost	(\$/pc)	31.93	17.27	0.00	7.69	0.00	11.16	0.00	0.00	27.73	-

Table 5: Comparison of Unit Manufacturing Cost

($/pc.)

Scheduling rule	Product1	Product2	Product4	Product6	Product9
LWKR	33.16	17.86	7.80	11.56	29.20
MWKR	30.45	16.57	7.56	10.68	25.97
TWORK	33.17	17.86	7.80	11.56	29.20
LTWORK	30.47	16.58	7.56	10.69	25.99
FCFS	34.99	18.74	7.97	12.15	31.38
SPT	31.93	17.28	7.69	11.16	27.73
FASFS	34.99	18.74	7.97	12.15	31.38

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