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DECISION MAKING ON MANUFACTURING SYSTEM FROM THE PERSPECTIVE OF MATERIAL FLOW COST ACCOUNTING

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ABSTRACT

Recently, significant research interest has been focused on environmental management aimed at the sustainable development of enterprises and society while decreasing the impact of such development on the environment. Japanese companies have been developing a variety of approaches and strategies. Material flow cost accounting (MFCA) has been proposed as a generally applicable indicator of growth potential and corporate environmental impact. Many companies that have introduced MFCA could recognize previously unnoticed losses. In addition, MFCA is useful as a tool to evaluate environmental impact and draft improved, more cost-efficient manufacturing plans. This paper demonstrates that companies that introduce MFCA can improve decision-making procedures and advantageously alter their manufacturing methods in a manner that differs from the inventory reduction idea based on the traditional Toyota production system.

1 INTRODUCTION

In recent years, social concern regarding environmental issues has been increasing. Thus, firms have begun to pay increased attention to environmental management, and the importance of environmental information is larger. It has become increasingly important to address how corporate management can address environmental impact concerns. MFCA is effective and represents one type of environmental management accounting that has already been introduced in several firms. The goal of this approach is to minimize material costs, the costs of processing waste material and energy consumption.

In this study, previously unrecognized losses are revealed using MFCA. In chapter three, the MFCA concept and its effectiveness are described. MFCA has been introduced at one factory. An examination of this company's MFCA use indicates that the method can improve a production system based on the Toyota production system (TPS).

A new idea derived from an MFCA analysis is reproduced in a simulation. The idea is that the quantity of raw materials that is not consumed in the manufacturing process is reduced instead of allowed to increase the existing stock or raw materials, contrary to the traditional principles of TPS inventory reduction. The production process model was designed using ARENA simulation software. Two types of simulation models were created which is an AS-IS model based on current production theory and a TO-BE model based on the novel production system concept based on MFCA analysis. By comparing these results, the idea's appropriateness could be quantitatively evaluated. In chapter 4, the procedure of considering new process improvements based on MFCA analysis and the design and verification of the simulation is presented. The process improvement based on MFCA displays advantages over the traditional production improvement concept. It is clearly demonstrated that this method is an effective decision-making tool.

2 BRIEF LITERATURE REVIEW

Simulation has traditionally been used as a decision-making tool for the improvement of manufacturing systems (Clymer 2000, Farahmand 2000). For many years, this approach has been regarded as a source of competitiveness for enterprises in the manufacturing sector that desire to increase production efficiency by eliminating waste according to the TPS (Monden 1998). This concept has spread outside Japan. Known as the lean production system, TPS is recognized as a standard production management method. However, the environmental impact of business activity has become a question of substantial interest to society. Large firms, including Toyota, Panasonic and Suntory, have exerted significant environmental management efforts (Kawaguchi 2011, Imamura 2011, Tomita 2011, Takaya 2011). There are many different approaches to environmental management. Several companies have introduced material flow cost accounting (MFCA), for example, Sekisui Chemical Group, Canon and the Tanabe Seiyaku pharmaceutical company (Numata 2011, Environmental Industries Office 2010). MFCA is used not only to determine losses but also indecision-making on capital investment, raw material procurement, product design, production planning and Kaizen activity (Kokubu 2002, Kokubu 2008). Although simulation research on production management has been performed from the MFCA perspective, the number of such studies remains limited (Tang and Takakuwa 2011, Tang and Takakuwa 2012).

3 MFCA: BASIC DESCRIPTION AND CASE STUDY

3.1 MFCA

Material flow cost accounting (MFCA) is an environmental management accounting tool aimed to simultaneously reduce environmental impact and costs. It may be a decision-making tool for business executives and on-site managers. MFCA seeks to decrease costs through waste reduction, thereby improving business and manufacturing productivity. MFCA measures the flow and the stock of "materials," which includes raw materials, parts and manufacturing process components, in terms of physical and monetary units. The costs are managed using the categories of material cost, energy cost, system cost, and waste treatment cost. The costs of losses incurred by defective products and waste and other emissions is identified through calculating their quantities and the resources used in each manufacturing process and converting the results into monetary values (Environmental Industries Office 2010). The MFCA concept is shown in Figure 1.

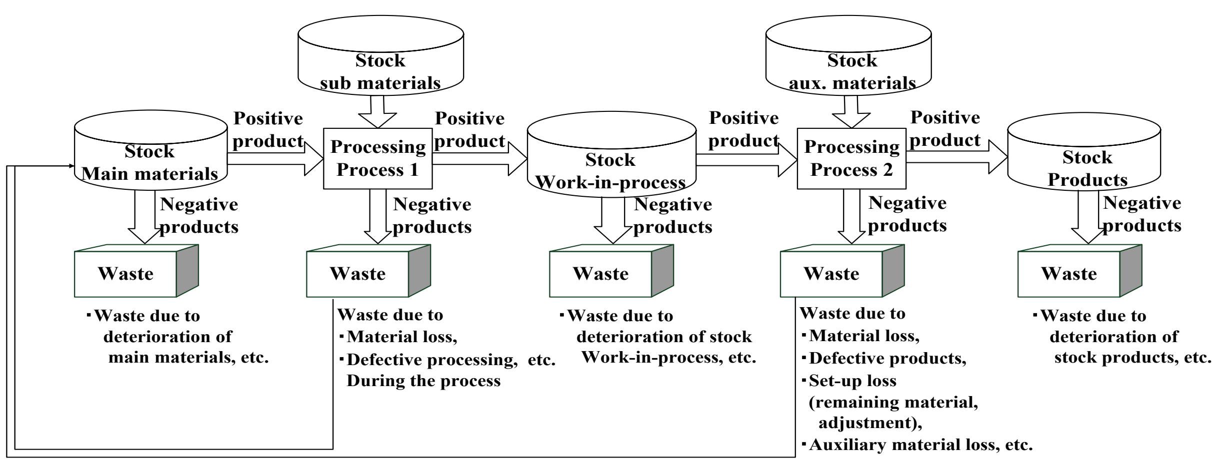

Figure 1: The MFCA concept (Environmental Industries Office 2007).

In the framework of MFCA, costs are calculated for good products and non-product output or material losses. Good products are usually called "positive products" and non-products or material losses are called "negative products." Costs of positive and negative products are categorized into four costs. Material costs are ones of material including main low material and sub material of additive, colorants, accessory and so on. System costs are ones of manufacturing system including labour and depreciation of equipment. Energy costs are ones of fuel such as oil or gas, electricity power, compressed or vacuum air, and water. Waste treatment costs are ones of detoxification.

In addition, in September 2011, ISO 14051 was published, and MFCA was internationally standardized. ISO 14051 clarifies the basic concept, the calculation method, and the implementation steps for MFCA. The standard's main purpose is to demonstrate the MFCA principle (Takakuwa et al. 2012).

3.2 Case Study

In this study, the research focus is an automobile parts manufacturer (Company T) located in Mie Prefecture, Japan. This company has developed and introduced an original production method developed from TPS. The factory is efficiently operated such that the quantity of stock is maintained as low as possible. The largest advantage of introducing MFCA at this factory has been the recognition of previously unnoticed losses and the determination of the amount of such losses. This factory produces automobile parts by cutting, heating, forging and heat-treating iron bars as well as quenching, shot blasting and machining. The company's factory layout is shown in Figure 2. For each process, a substantial number of machines are used. In this factory, secondary material, such as coolant, sand and oil, is used in each process. The material and waste flow is shown in Figure 3.

Because the loss is calculated based on the weight of material in MFCA, the quantity center, which represents the measured weight of the material, is important. There are four quantity centers, which include raw material, WIP and waste as follows: (A) the cutting process, in which cut iron bar is the primary material; (B and C) the heating and forging process, in which cut iron columns are heated, forged and punched; (D and E) the heating treating and shot-blasting process, in which the surface is hardened and the scaling is removed; and (F and G) the lathing and machining process, in which the machining of the finished product is performed. The reason why heating and forging are defined as belonging to the same quantity center is because these processes are performed using the same equipment line, as are lathing and machining. The reason why the heating and treating processes are defined as belonging to the same quantity center is because weight change does not occur and failed work pieces are not found because there is no inspection process between heating treating and shot blasting.

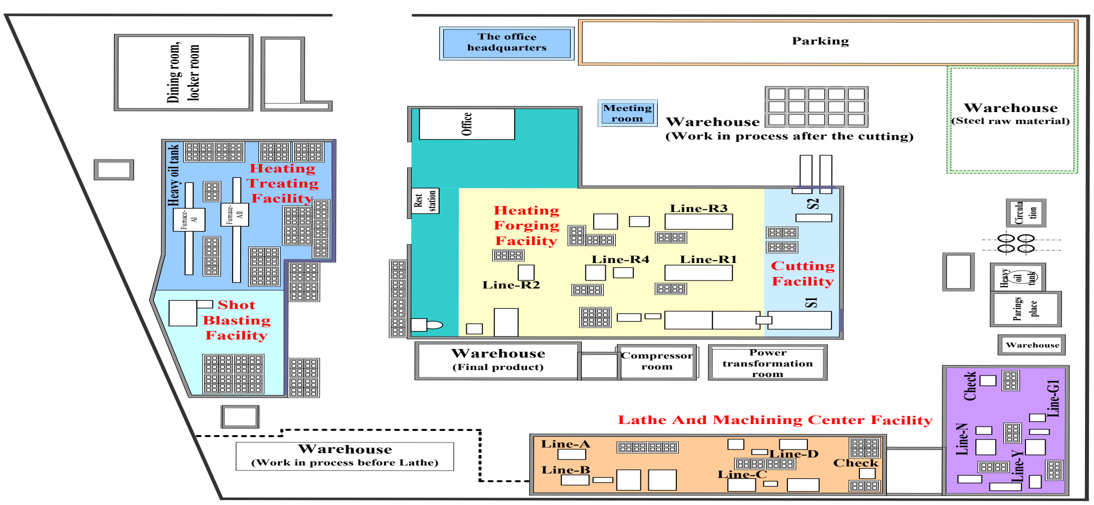

Figure 2: Factory layout.

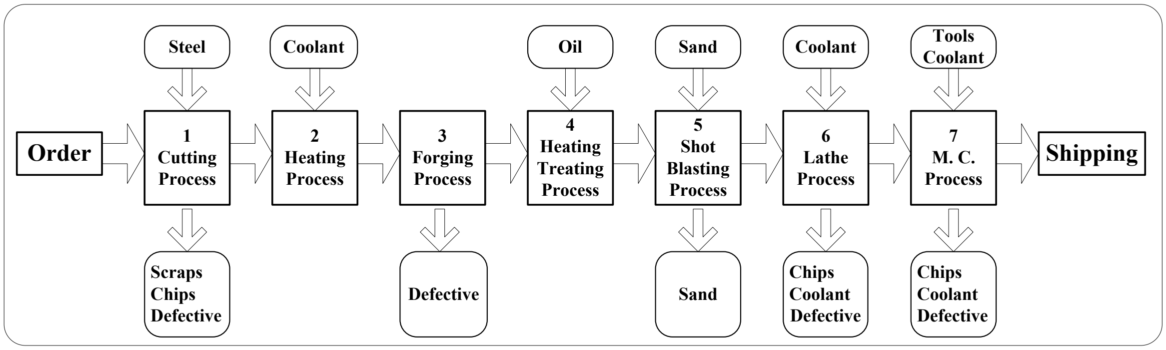

Figure 3: Material and waste flow at Company T.

3.3 MFCA Analysis

First, material and other costs were calculated by MFCA analysis as shown in Table 1. The material costs an analysis is performed by inputting data such as the unit price of raw materials, the quantity of introduced raw materials, the number of positive (i.e., non-defective) products and negative products, such as chips and defective products. The system cost is calculated based on the labour, tool and coolant costs, among others, that are allocated to each process. Energy use, such as electric power, heavy oil, light oil and LNG, as well as water use are similarly assessed by calculating the energy cost. As the result, the positive product cost was determined to be 71.4%, as shown in Figure 4. This outcome indicates that 28.6% of the total input costs have not became product and have been discarded.

Table 1: Raw material data.

			QC1	QC2	QC3	QC4
Input	Intermediate product	(kg)	0.0	47,448.5	44,171.4	44,160.5
	Main material	(kg)	49,036.0	2,273.2	0.0	1,868.3
Output	Finished product (conforming)	(kg)	47,448.5	47,164.7	44,160.5	34,988.8
	Finished product (loss)	(kg)	1,587.5	2,557.1	10.9	11,040.0

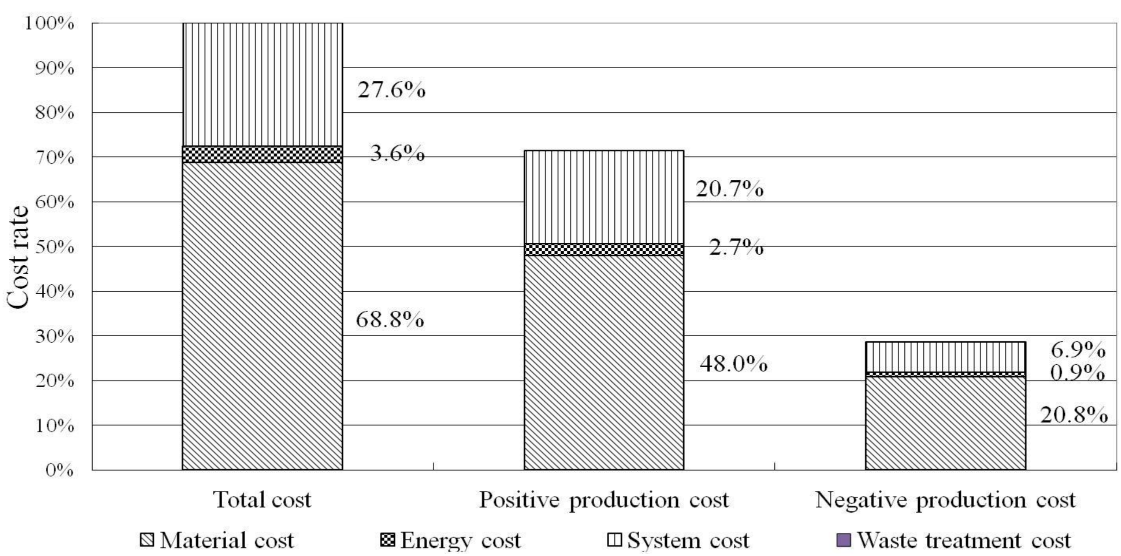

Figure 4: MFCA analysis results.

4 THE SIMULATION MODEL AS A DECISION-MAKING TOOL

4.1 The Search for an Optimal Solution from the MFCA perspective

A novel process improvement idea based on MFCA analysis is compared with conventional process improvement. Traditionally, TPS has been used in process improvement. TPS defines 7 categories of waste: waste of defects, over-production, waiting, transportation, processing, inventory and motion. Increased production efficiency by the elimination of waste is becoming a resource of growth potential in firms.

Particularly in recent years, inventories may require not only stock administration costs but also may become dead stock because the product life cycle has become shorter. It has been a standard theory of manufacturing to reduce inventory and production costs by the precise timing of sales. In fact, automobile parts manufacturing Company T makes different shapes of the final product to reduce the amount of work in process (WIP) inventory. The method used is to cut the product to its final shape in the machining center process after all of the parts have been prepared similarly. In the manufacturing sector, such approaches are referred to as formulas. As shown in Figure 5, this concept means that Part X is designed to a size that is as close to the size of Part A as possible, and Part B is produced by taking advantage of machining center allowances.

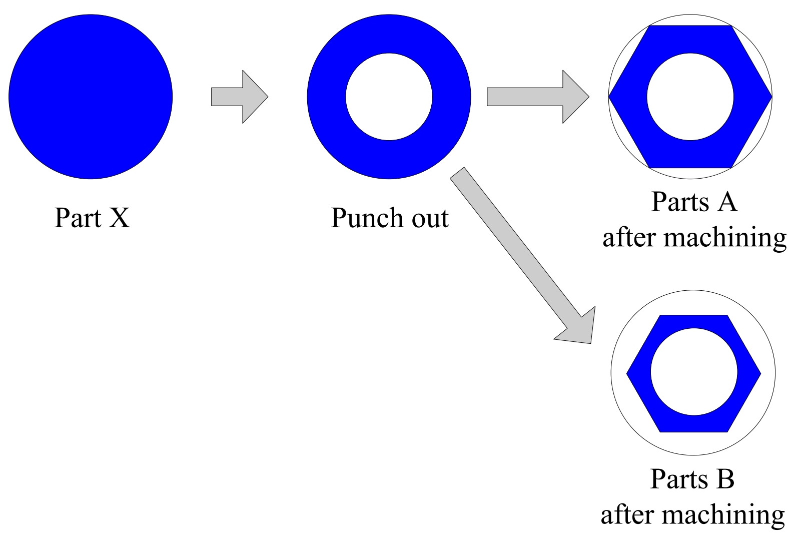

Figure5: The concept of current relationship of the WIP and finished product (AS-IS model).

However, from the MFCA perspective, the magnitude of the negative product cost when producing Part B increases the environmental impact because additional metal resources are required as raw material and as a result of other associated costs, such as an increase in the amount of waste treatment, the number of spent cutting tools, coolant, chips and energy loss.

This study proposes a procedure to determine the optimum process by calculating the costs and environmental impact while comparing the AS-IS and TO-BE models. The AS-IS model is the current production process, in which semi-finished products are produced until the midpoint of the production stream is reached. The TO-BE model is the actual current production model in which the shape of the product is as close to that of the final product as possible from the beginning of production stream (Figure 6). The current process is known as the AS-IS model. Two types of final product (M1 and M2) are used to represent the machining center process, which is the end of the process in the AS-IS model. M1 and M2 are manufactured as two varieties from the beginning in the TO-BE model. M1 involves a small amount of cutting and M2 a large amount of cutting during the machining center process to produce the same part that is produced from the cutting process to shot-blasting process in the AS-IS model. At Company T, the cutting amount for M1 is 24%, whereas for M2, the amount is 38%. However, the negative cost generated during the machining process is avoided in the TO-BE model because M1 and M2 are manufactured as two varieties from the beginning.

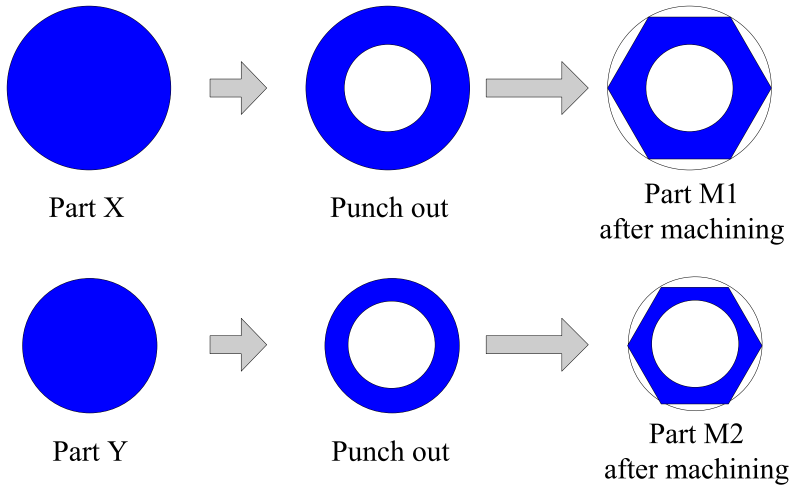

Figure 6: The concept of shaping the final product according to the upstream process (To-Be model).

In the TO-BE model, maintenance is required for each M1 and M2 WIP from the start of production. It is assumed that WIP inventory maintenance costs increased by 20%. Various changes are simulated on the condition that M1's machining waste rate is the fixed-rate of 24%. In addition, in Table 2, it was assumed that the machining time shortened as the amount of cutting of M2 was decreased.

Table 2: The simulation conditions.

Models	Machining waste rate		MC processing time (Second) TRIA (Min, Mode, Max)		
	M1	M2	Min	Mode	Max
AS-IS model	24%	38%	414.0	444.0	445.0
TO-BE model 1	24%	37%	413.3	434.2	435.1
TO-BE model 2	24%	36%	412.6	442.5	443.5
TO-BE model 3	24%	35%	411.9	441.7	442.7
TO-BE model 4	24%	34%	411.2	441.0	442.0
TO-BE model 5	24%	33%	410.5	440.2	441.2
TO-BE model 6	24%	32%	409.8	439.5	440.5
TO-BE model 7	24%	31%	409.1	438.7	439.7
TO-BE model 8	24%	30%	408.4	438.0	438.9
TO-BE model 9	24%	29%	407.7	437.2	438.2

Models	Machining waste rate		MC processing time (Second) TRIA (Min, Mode, Max)		
	M1	M2	Min	Mode	Max
-	-	-	-	-	-
TO-BE model 10	24%	28%	407.0	436.4	437.4
TO-BE model 11	24%	27%	406.2	435.7	436.7
TO-BE model 12	24%	26%	405.5	434.9	435.9
TO-BE model 13	24%	25%	404.8	434.2	435.1
TO-BE model 14	24%	24%	404.1	433.4	434.4
TO-BE model 15	24%	23%	403.4	432.7	433.6
TO-BE model 16	24%	22%	402.7	431.9	432.9
TO-BE model 17	24%	21%	402.0	431.1	432.1
TO-BE model 18	24%	20%	401.3	430.4	431.4

4.2 Proposed Simulation Procedure

A simulation model based on the current manufacturing process was created to determine whether there is any effect when the improvements generated by MFCA analysis are implemented. The simulation programs were written in ARENA. ARENA can handle continuous, discrete and mixed models and is particularly suitable for the simulation of discrete events that involve steps at discrete points in time. ARENA is the most appropriate software for this type of system because the arrival time for the work, the processing time and other events are retrieved as discrete information (Kelton, Sadwski and Swets 2010). Furthermore, ARENA has a satisfactory record in terms of empirical research on process improvement. Figure 7 shows the primary logic of the simulation model.

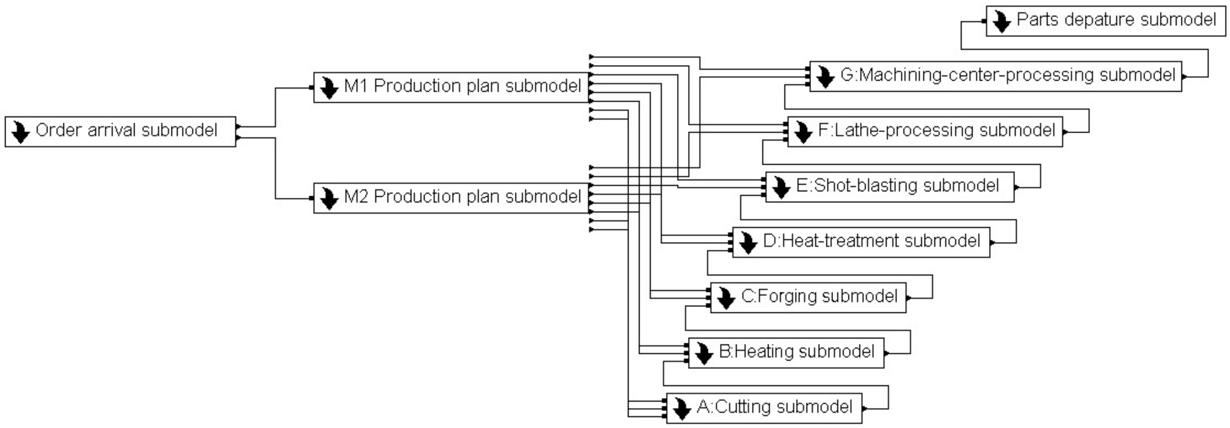

Figure 7: Primary logic of simulation model.

The primary logic is composed of 11 submodels, which include order arrivals, production plans, each process and the parts departure. Production is started by the arrival of the order. Production plan is set up by the kind of products. This plan will issue a production order to the respective processes. Production is completed in all the products that will be shipped.

Figures 8 and 9 show the logic of the simulation submodel. Each step of the process occurs as a submodel, which combine to comprise the entire simulation model. The order number, delivery time and quantity are defined by order information. It is planned that set up time and production time of each process, production lot number, the number of WIP and so on. Cutting and each process submodel is defined amount of product weight, process time, default rate, waste rate, material cost, energy cost, recipe and so on in each production process.

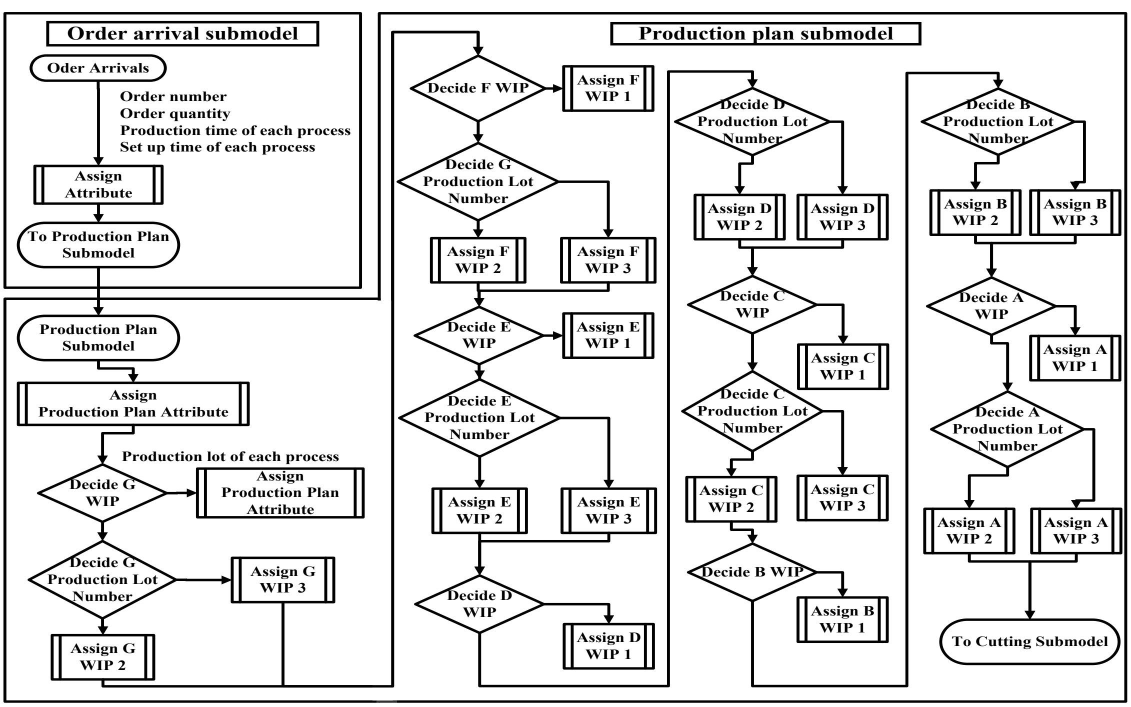

Figure 8: Primary logic of simulation submodel of order arrival and production plan.

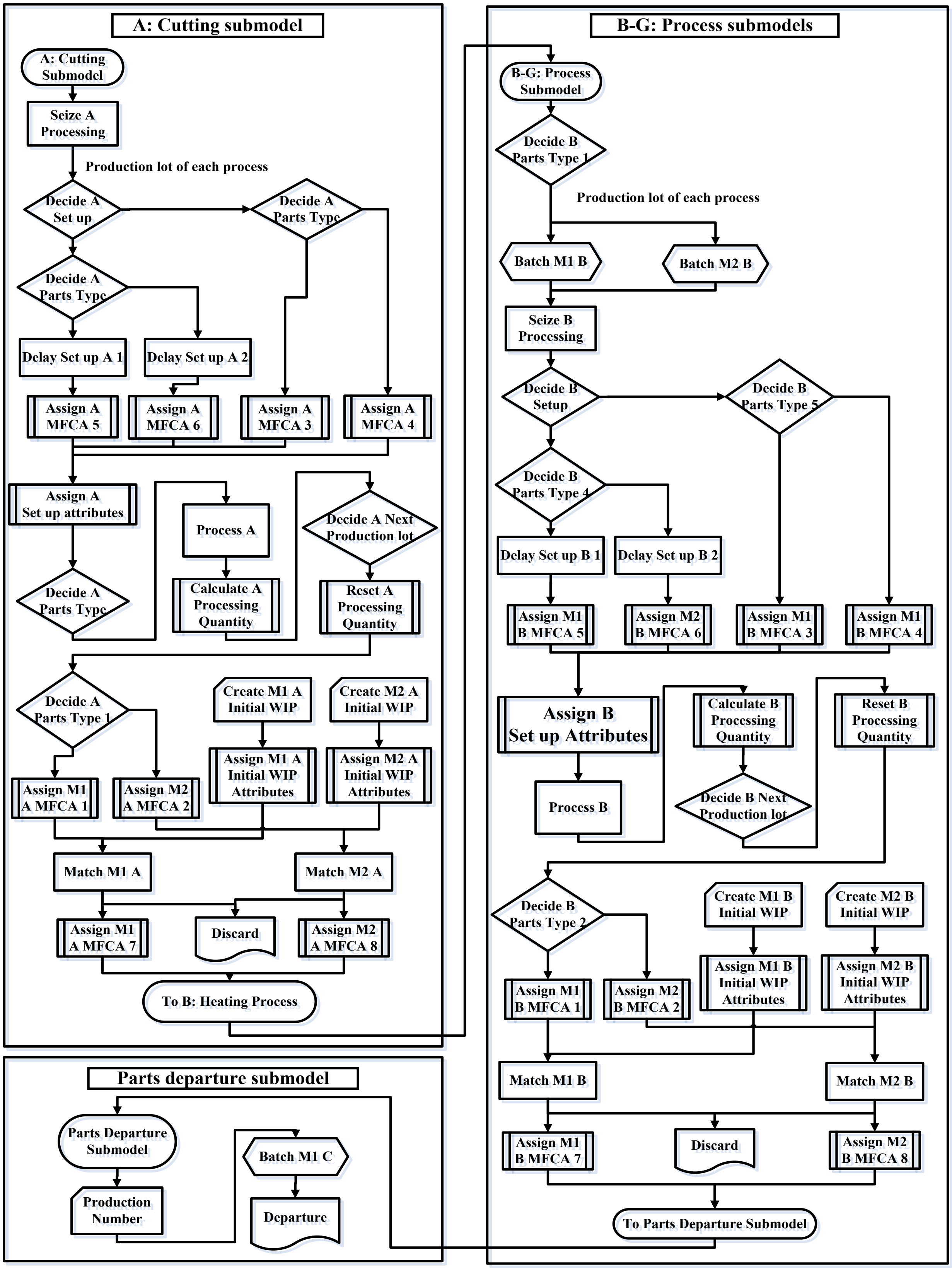

Figure 9: Primary logic of simulation submodel of each process and parts departure.

4.3 Results

As shown in Figures 10 and 11, the total cost is reduced by decreasing the negative production cost. For example, according to the simulation results, cutting waste and costs are reduced by increasing stock and inventory management costs. The total cost is the lowest for TO-BE model 16, followed by TO-BE models 18 and 9. The waste rate of M2 during the machining process is 22%, 20% and 29%, respectively. The decision to accept a 1.2 times increase in the inventory maintenance cost and a 22% waste rate for M2 were valid cost reduction measures. TO-BE model 16 results in a positive production cost rate increase of approximately 3.5 points from the 77.13% of the AS-IS model to 80.62% (Figure 10). The results indicate that decision-making based on a MFCA simulation was cost-effective. Decision-making based on the MFCA perspective achieved cost reduction and improved environmental management according to the method described above and the quantitative evaluation of the effects of MFCA on production.

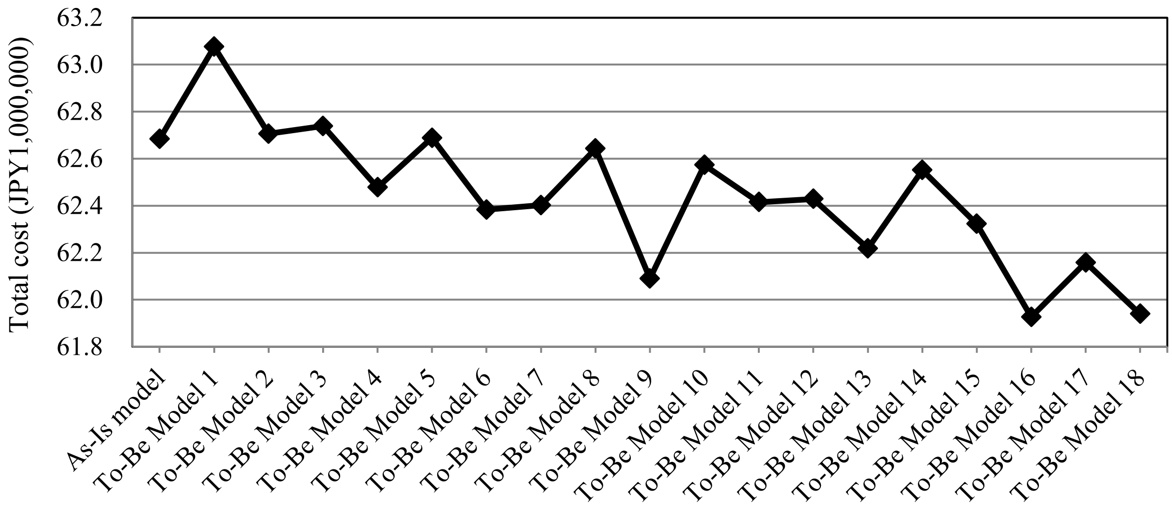

Figure 10: Total cost.

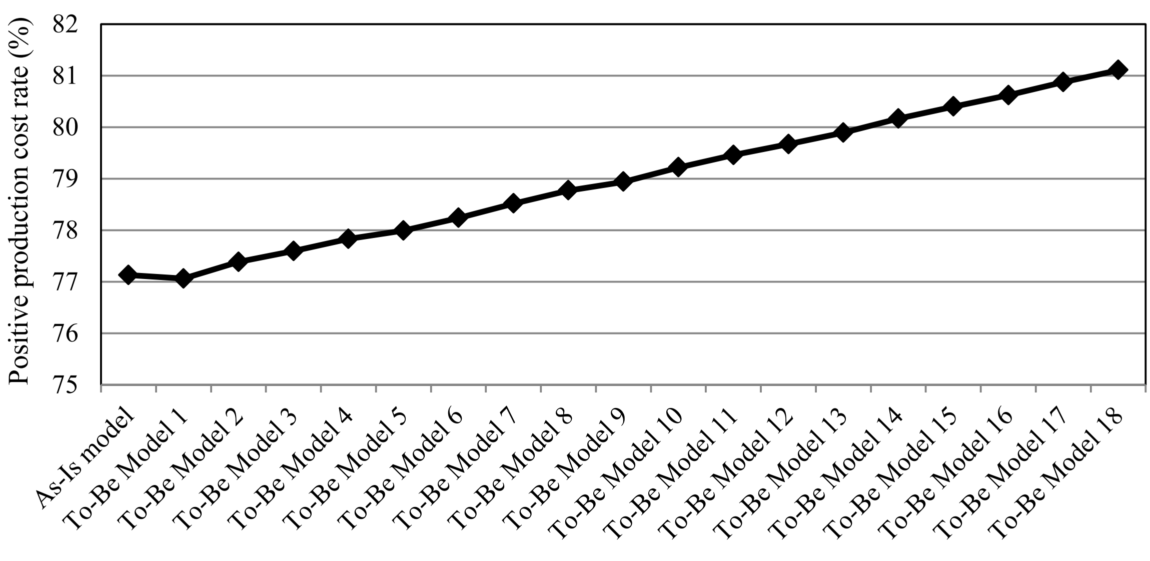

Figure 11: Positive production cost rate.

5 CONCLUSIONS

It was demonstrated that unrecognized loss can be revealed by introducing the MFCA method, which differs from the traditional TPS formulas. The insight that MFCA provided resulted in innovative suggestions for improving the manufacturing process. In addition, it has been demonstrated that the effectiveness of traditional production methods, such as TPS, compared with that of new ideas based on MFCA could be quantitatively evaluated using simulations, the procedure for which was described. The simulation results, particularly with respect to production costs, can be used advantageously in economic decision-making. The change of positive and negative costs determined using MFCA contributes significantly to the execution of environmental management as an indicator of the effective utilization rate of resources and the burden of waste and loss disposal. This proposed application is available for decision-making of size of law material at the stage of product design, combination of variety for products at the stage of production planning and upgrading manufacturing. It may be usable for decision-making on alternatives of building new factory in emerging countries or promote cost reduction in existing factory.

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REFERENCES

Clymer, J. R. 2000. “Optimizing Production Work Flow Using OpEMCSS.” In *Proceedings of the 2000 Winter Simulation Conference*, Edited by J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 1305–1314. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc. ISBN: 0-412-83930-X.

Environmental Industries Office, Industrial Science and Technology Policy and Environment Bureau, Ministry of Economy, Trade and Industry of JAPAN. 2007. “Guide for Material Flow Cost Accounting (Ver.1).” http://www.meti.go.jp/policy/eco_business/pdf/mfca%20guide20070822.pdf

Environmental Industries Office, Industrial Science and Technology Policy and Environment Bureau, Ministry of Economy, Trade and Industry of JAPAN. 2010. “*Material Flow Cost Accounting MFCA Case Examples*. ”http://www.jmac.co.jp/mfca/thinking/data/MFCA_Case_example_e.pdf

Farahmand, K. 2000. “Using Simulation to Support Implementation of Flexible Manufacturing Cell.” In *Proceedings of the 2000 Winter Simulation Conference*, Edited by J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 1272–1281. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Imamura, S. 2011. “Environmental Management of Toyota Motor Corporation.” *The Japan Society for Quality Control* 41(1): 23-28. (In Japanese)

Kawaguchi, T. 2011. “Toyota Environment Actions.” *Japan Society for Information and Management* 31(4): 55-62. (In Japanese)

Kelton, W. D., R. P. Sadowski, and N. B. Swets. 2010. *Simulation with ARENA.* 5th ed. New York: McGraw-Hill, Inc.

Kokubu, K. 2008. *Material Flow Cost Accounting.* Tokyo: Japan Environmental Management Association For Industry (In Japanese)

Kokubu, K. 2010. “Production and Environment Management through Material Flow Cost Accounting.” *Japan Society for Information and Management* 31(2): 4–10. (In Japanese)

Kokubu, K., and H. Tachikawa. 2012. “Material Flow Cost Accounting.” In *Manufacturing and Environmental Management*, Edited by S. Takakuwa. 265–283. Hanoi: National Political Publishing House. ISBN: 987-604-57-0000-6.

Monden, Y. 1998. *Toyota Production System*. 3rd ed. Norcross, Georgia: Institute of Industrial Engineers.
Numata, M. 2011. "The Introduction of the Material Flow Cost Accounting in the Manufacturing Development Innovation of the Sekisui Chemical Group." *Japan Society for Information and Management* 31(4): 83-88. (In Japanese)
Takaya, M. 2011. "'Suntory, Bringing Water to Life' environment protection activities." *The Japan Society for Quality Control* 41(1):13-18. (In Japanese)
Tang, X., and S. Takakuwa. 2011. "Simulation Analysis for ERP Conducted In Japanese SMEs Using The Concept of MFCA." In *Proceedings of the 2011 Winter Simulation Conference*, Edited by B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan, 2089–2100. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.
Tang, X., and S. Takakuwa. 2012. "MFCA-Based Simulation Analysis for Environment-oriented SCM Optimization Conducted by SMEs." In *Proceedings of the 2012 Winter Simulation Conference*, Edited by C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhrmacher, Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.
Tomita, K. 2011. "The Panasonic's Environmental Management of Panasonic." *The Japan Society for Quality Control* 41(1): 33-38. (In Japanese)

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