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MFCA-BASED SIMULATION ANALYSIS FOR ENVIRONMENT-ORIENTED SCM OPTIMIZATION CONDUCTED BY SMES

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ABSTRACT

The environmental and economic benefits of Small and Medium Sized Enterprises (SMEs) are rarely considered during supply chain optimization. In this study, using the concept of Material Flow Cost Accounting (MFCA), an AS-IS simulation model for the supply chain comprising a Japanese gear manufacturing SME and its customer was constructed to visualize the enormous amount of waste generated by the production process. A TO-BE simulation model for the process innovation plan conducted by the above SME confirmed that the reduction in the machinery allowance and in the production lead time of the entire supply chain could be achieved, which will provide environmental and economic benefits to the entire supply chain.

1 INTRODUCTION

In the context of activities that promote environmental protection, many larger enterprises are transferring production processes with fewer added values to SMEs, and these changes may cause pollution issues for SMEs. The environmental and economic benefits of SMEs are rarely considered during supply chain optimization. To achieve truly global environmental protection, it is important to examine the performance of the entire supply chain and its economic and environmental effectiveness from the perspective of SMEs.

The SME examined in this study is a Japanese gear material manufacturing enterprise ("Company A"), which is a contract manufacturer for a world-famous heavy machinery producer ("Company S"). Both of the companies suffer from the problems of delayed deliveries and increased stock caused by the excessive demands and frequently changing small-lot orders of their customers. Increased stock will cause a huge amount of future additional corrective actions that may create a substantial environmental burden.

In this study, a simulation model is constructed using the ARENA software to simulate these problems in the two companies and to identify and examine solutions to these problems. In addition, the concept of Material Flow Cost Accounting (ISO14051) was introduced into the model to evaluate the environmental performance of the target production processes. By using the new powerful method of environmental management accounting, significant waste (called "negative products" in the MFCA concept) was identified in the hole-drilling process. This practice produces a large environmental burden by generating a useless machining allowance and increasing the production lead time, which generates economic inefficiency.

To solve the above problem, a process innovation plan was implemented by Company A that involves changing the hole-cutting method from drilling to forging to take advantage of the high processing speed and near-net shape provided by the forging process. The environmental and economic effectiveness of the innovation plan was confirmed by constructing the TO-BE simulation model (which represents the improved situation).

2 RESEARCH APPROACH: MFCA

Company activities such as environmental preservation often lead to increased costs. Enterprises, however, focus on profit and economic efficiency. Recently, the development of environmental accounting systems has advanced, and these systems have been praised as being powerful methods for improving economic efficiency while simultaneously protecting the environment. In particular, Material Flow Cost Accounting (MFCA) has received considerable attention for its effectiveness (Environmental Industries Office 2010).

MFCA is a system used to measure the flow and stock of materials in the manufacturing process (raw materials and energy) in terms of physical and monetary units (Kokubu 2008). The prototype of MFCA was developed in Germany as an environmental protection accounting technique. Since the introduction of MFCA in Japan in 2000, great progress has been made regarding the application of MFCA to the activities of Japanese enterprises (Environmental Industries Office 2007). For the international standardization of MFCA, The Ministry of Economy, Trade and Industry in Japan proposed the New Work Item Proposal TC207 (to the environmental management category) to the International Organization for Standardization (ISO) in November 2007. After the proposal was adopted in March 2008, a working group for standardization was established and began work on the international standardization issue. The MFCA standard was granted ISO 14051 by the ISO secretariat in September, 2011, and MFCA has since attracted attention in Japan and worldwide (Environmental Industries Office 2010).

The concept of MFCA is shown in Figure 1.The manufacturing enterprise stocks raw materials, manufactures products through the production activities, and supplies them to the market. These products are considered as positive products in MFCA. Waste is also generated during the process of stocking and production because the materials that are stocked as inventory may deteriorate in quality or be replaced, and these materials or parts are no longer useable for production. When the materials are processed, residues or shavings may be generated. Under the circumstances mentioned above, these materials are considered waste. Because they may lead to environmental problems, in the concept of MFCA, these materials are treated as negative products and are considered a loss (Tang and Takakuwa 2011).

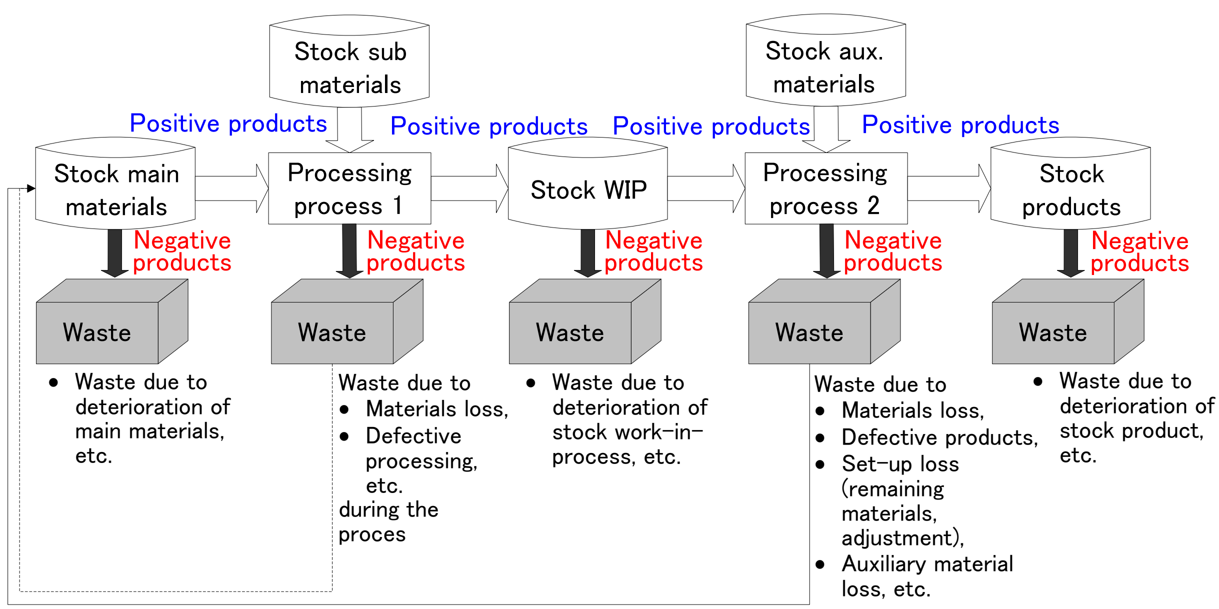

Figure 1: The concept of MFCA (Environmental Industries Office 2007)

The costs of both positive products and negative products are composed of the following four kinds of costs:

(1) Material costs, MC, including main materials put in from the initial process, sub materials put in during midstream processes, and auxiliary materials such as detergents, solvents and catalysts.
(2) System costs, SC, are processing costs, including labor, depreciation, overhead costs, etc.
(3) Energy costs, EC, include electricity, fuel, utility and other energy costs.
(4) Waste treatment costs.

A lot of practical applications have shown that by introducing MFCA, companies can improve both environmental performance and economic performance. However, examples of MFCA implementation in SMEs are still lacking (Environmental Industries Office 2010, Tang and Takakuwa 2011).

3 CASE STUDY AND AS-IS MODEL CONSTRUCTION

3.1 AS-IS Model Reflecting the Actual Conditions of the Researched Target

In this study, the main research target is a contract manufacturer (Company A, located in Niigata Prefecture, Japan) for a world-famous heavy machinery producer (Company S, located in Aichi Prefecture, Japan). The study focuses on the main business flow and part of the manufacturing process of four types of gears manufactured by the two companies, which is shown in Figure 2 and described below:

(1) Unofficial Notifications - Rough Production Plan: When the unofficial notifications are given by Company S, Company A will check stock conditions (especially the inventory of steel cylindrical bars and semi-processed products that had been produced through the forging process). Company A will create the material purchasing plan and the semi-processed product plan, which is called the Rough Production Plan. Based on the rough production plan, the production instructions for the cutting process and the forging process are created.
(2) Orders - Detailed Production Plan: While the real orders are being received, Company A will create a Detailed Production Plan. Based on this plan, the production instructions for the heating treatment process through the surface lathing are created by Company A. After the surface lathing process is finished, the products are delivered to Company S. Company S continues the hole-drilling process using the machining centers (MC).

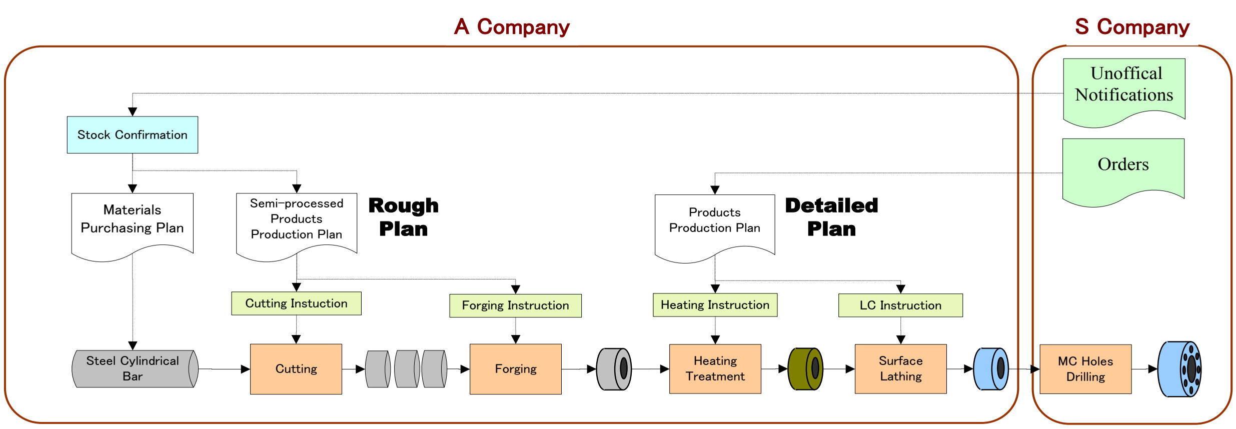

Figure 2: Business flow and manufacturing process of Company A and Company S

Because the demands for the gears are large, the orders from Company S's customers consist of various products in small quantities, and notification information is changed by the customers frequently, both Company S and Company A have problems with delayed deliveries and overstocks.

To reflect the detailed operating situation of the production processes, an AS-IS simulation model of the business flow of the two companies was constructed. There are some powerful expert simulation tools like Umberto that were developed to master the production processes and material and energy flows or carbon footprints during the enterprises' manufacturing activities to perform environmental analysis (Ifu Hamburg GmbH 2010). In this study, simulation package ARENA was used to build simulation models of the manufacturing process considering both the economic and environmental aspects (Kelton, Sakowski, and Swets 2010). For evaluating economic performance, the key indices are selected as follows:

(1) Production lead time: An average production lead time for a single order, which reflects the production efficiency and is the essential index that influences the following other indices.
(2) Finished orders: The quantity of the orders for which all of the production processes are finished, which influences the revenue of the enterprises directly.
(3) Delayed orders: Among the finished orders, the orders for which the actual production lead time is longer than the delivery time required by the customers. This index influences the customers' satisfaction.
(4) WIP Inventory: This index represents a financial balance of the enterprises.

The production processes of four typical products were selected for the model construction. Table 1 shows the orders' requirements and the contents of each product, and Table 2 shows the different production times and lots in the different production processes.

Table 1: The orders' requirements and the contents of each product

Product Type	**M1**	**M2**	**L1**	**L2**
Order Frequency (hours)	every 48	every 56	every 56	every 24
Delivery Time (hours)	240	240	240	240
Order Lot (pieces)	72	72	12	12

Table 2: Production times and lot sizes in the different production processes

Product Type	**M1**		**M2**		**L1**		**L2**	
Production Sequence	**Lot Size**	**Time (hours)**	**Lot Size**	**Time (hours)**	**Lot Size**	**Time (hours)**	**Lot Size**	**Time (hours)**
1) Cutting Process	38 pcs.	4	36 pcs.	3.79	36 pcs.	3.89	33 pcs.	3.88
2) Forging Process	47 pcs.	1.1	47 pcs.	1.2	47 pcs.	1.54	47 pcs.	1.6
3) Heat Treatment	4,666 kg	24	4,666 kg	24	4,666 kg	24	4,666 kg	24
4) Surface Lathing	72 pcs.	7.14	72 pcs.	6	12 pcs.	9.58	12 pcs.	9.9
5) MC Process	72 pcs.	9.54	72 pcs.	8	12 pcs.	17.62	12 pcs.	14.46

The model is comprised of the following six sub-modules, as shown in Figure 3:

(1) Order Arrivals: In this sub-module, unofficial notifications and orders are generated and addressed with different order numbers, product quantities, structures of materials, delivery times, and so forth.
(2) Cutting Process: Cutting instruction is established according to the present inventory level of semi-processed products and the total demand for products calculated in the first sub-module.
(3) Forging Process: After the cutting process is finished, the products are sent to the forging process machines. In this module, the process is divided into two sub-processes: preheating and pressing. It should be noted that the processes of modules (2) and (3) are guided by a rough production plan formulated according to the unofficial notifications. Modules (4) through (6) are guided by a detailed production plan that is formed according to the real, final orders.
(4) Heating Treatment: It takes 24 hours to change the hardness of the steel through this process.
(5) Lathe Process: The products' surfaces are lathed precisely in this process.

(6) MC Process: During this process, the surrounding holes, called D holes, are drilled. A large machining allowance is generated that increases the environmental burden.

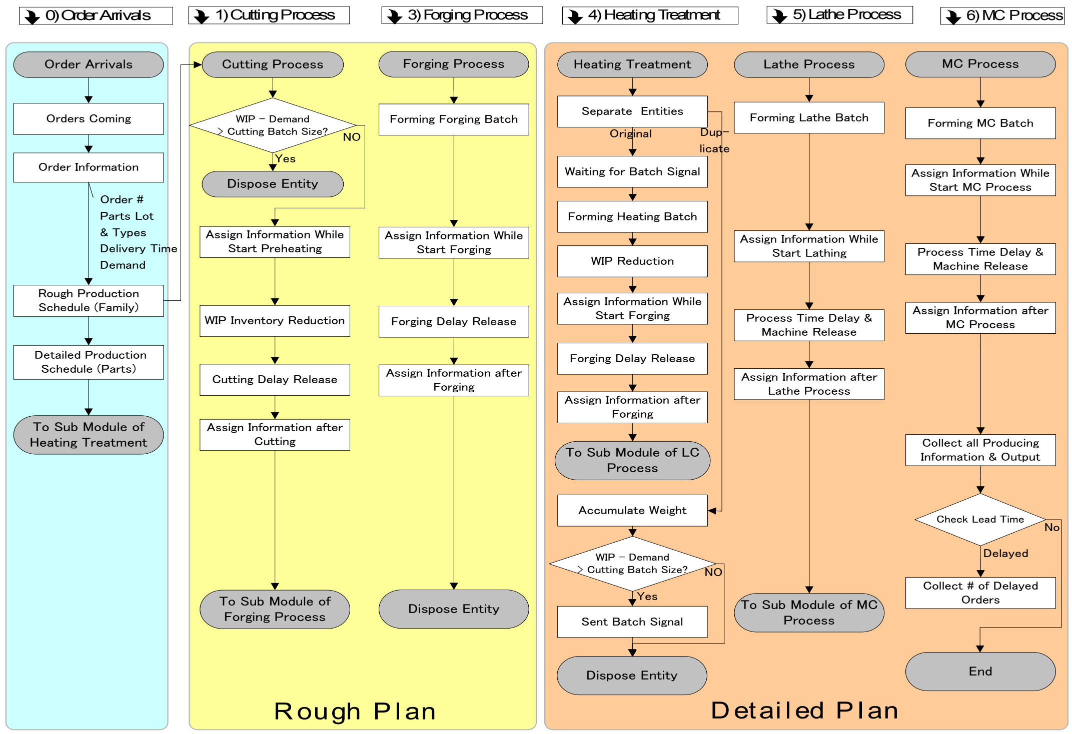

Figure 3: The logic of the AS-IS simulation model

Figure 4 shows an animation of the operating situation of the AS-IS model. The left part of the illustration, labeled “WIP”, shows the changing semi-processed product (called WIP) inventory level, which is demonstrated by both the plots and the figures. The middle part shows the implementation of the production processes. The figures labeled “finished orders” and “delayed orders” show the ability to fulfill orders.

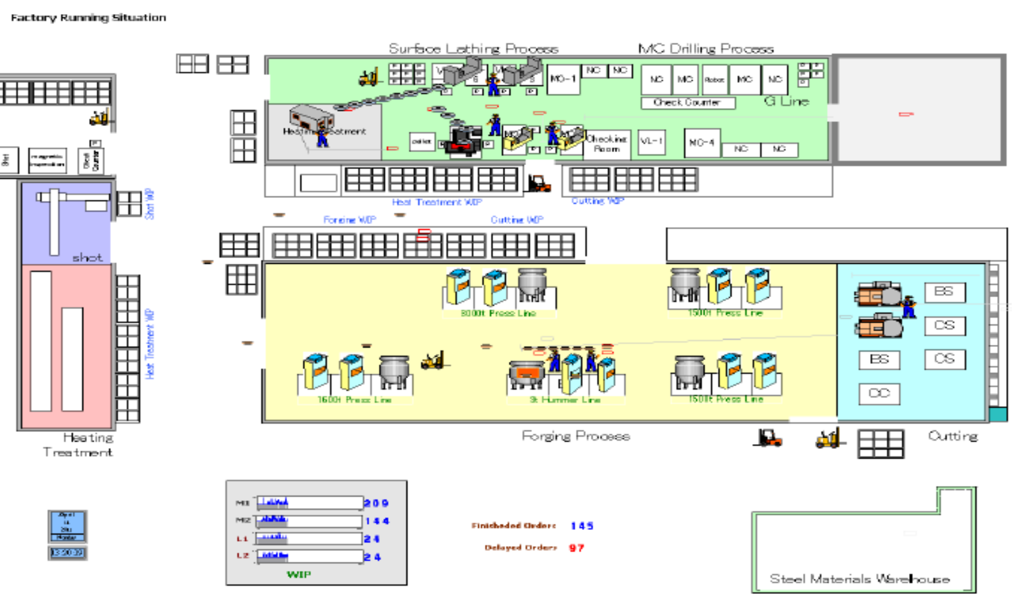

Figure 4: Animation of the AS-IS simulation model

The AS-IS model was executed 100 times, with the run length assumed to be 1 year. The average results at the 95% confidence level are shown in Table 3. It can be seen that most of the finished orders are delayed, and the quantity of the WIP inventory is almost 2.5 times as many as those in the case of a single order, as shown in Figure 5 and Figure 6. These results show that the current production capacity cannot meet the demand for orders. To resolve the capacity problem and to manage emergency orders, Company A must produce the WIP beforehand according to the unofficial notifications, which may be changed or cancelled by customers in the future and cause the overstock problems. Furthermore, overstocks could cause financial problems and produce scrapped waste, increasing the environmental burden. Figure 6 shows that the WIP inventory levels at both the term-end and during the period remain high.

Table 3: Order fulfillment conditions

KPI	Results
Production Lead Time (hours)	330
Finished Orders (orders)	690
Delayed Orders (orders)	356

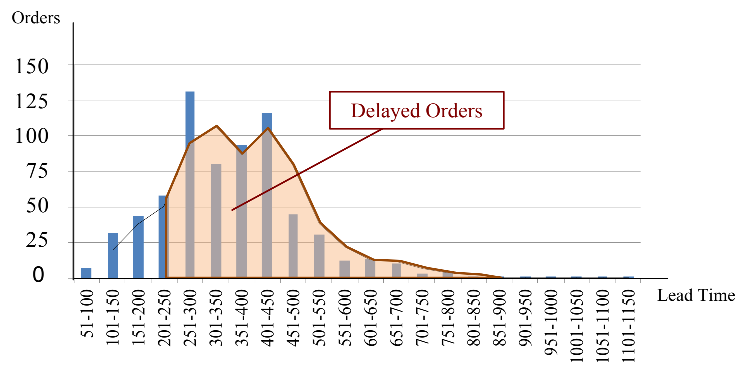

Figure 5: The distribution of the production lead time of different orders

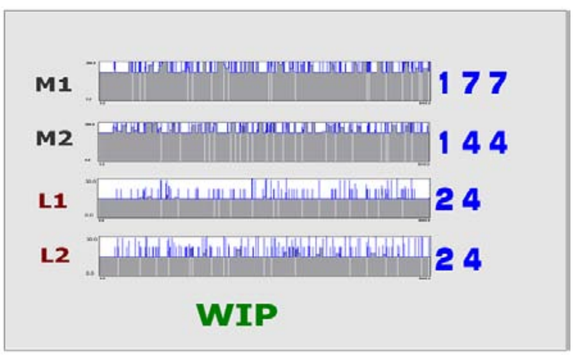

Figure 6: The WIP inventory levels at both the term-end and during the period

Measures, such as the optimization of production scheduling or resource investment, can increase the capacity, which could solve both the capacity problem and the stock problem. First, however, it is important to determine whether there are hidden losses or waste during the production process. Therefore, in-process evaluation techniques should be introduced into the model. Recently, MFCA has received considerable attention for its effectiveness. The concept of MFCA can be used to reconstruct the model and to visualize the hidden waste of the researched production process.

3.2 AS-IS Simulation Model Using the Concept of MFCA

The above-mentioned concept of MFCA was introduced in the AS-IS simulation model by adding the cost calculations. Table 4 shows the weight of the input material and the output-positive products at each process.

Table 4: Weight of the input material and the output-positive products at each process

Product Type	M1		M2		L1		L2	
Production Sequence	Input Material (kg)	Output Material (kg)	Input Material (kg)	Output Material (kg)	Input Material (kg)	Output Material (kg)	Input Material (kg)	Output Material (kg)
1) Cutting Process	11.37	10.7	11.86	11.2	22.64	20.8	23.81	22.5
2) Forging Process	10.7	8.76	11.2	9.35	20.8	18.3	22.5	19.3
3) Heat Treatment	8.76	8.76	9.35	9.35	18.3	18.3	19.3	19.3
4) Surface Lathing	8.76	6.36	9.35	8.39	18.3	13.53	19.3	14.5
5) MC Process	6.36	4.335	8.39	6,65	13.53	8.166	14.5	9.848

Figure 7 shows both the positive and negative costs in the different production processes. As the products are processed more, the associated amounts increase.

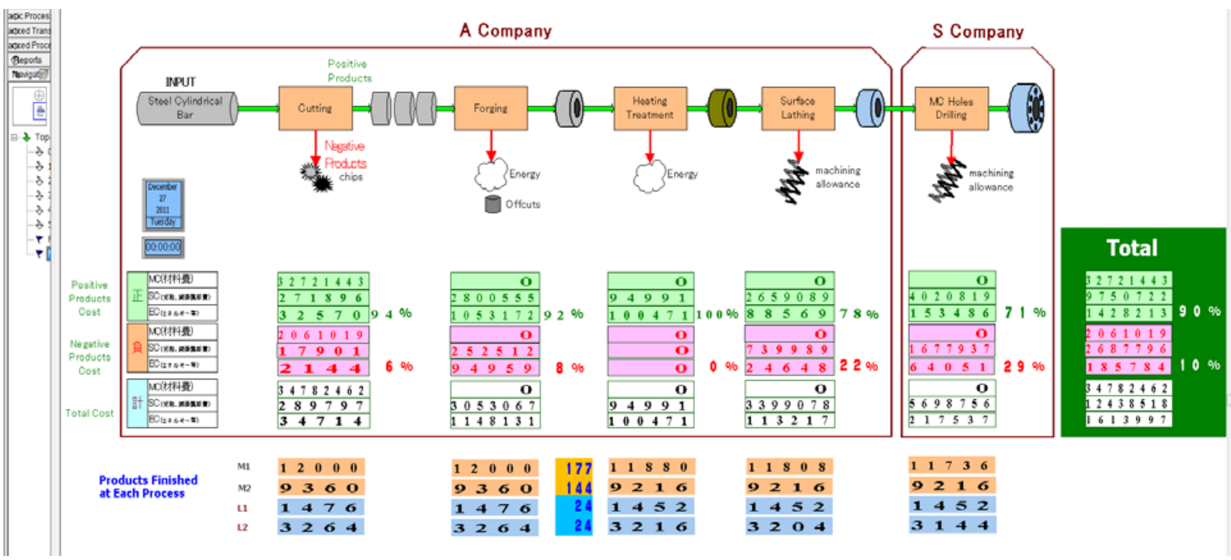

Figure 7: Animation of the AS-IS model using the concept of MFCA.

The model was executed 100 times, with the run length assumed to be 1 year. The results (at the 95% confidence level) are shown in Table 5.

Table 5: Simulation executing results of MFCA (Unit: thousand JPY)

	Cutting Process	Forging Process	Heating Treatment	Surface Lathe	MC Process
Positive Products Cost	306 (32,810) *	3,796	199	2,704	4,130
Negative Products Cost	20 (2,071) *	340	0	740	**1,721**
Total Cost	326 (34,882) *	4,136	199	3,444	5,851
Negative Products Cost Rate	6%	8%	0%	21%	**29%**

*: The values in the parentheses are calculated including the costs of the main materials. Because all of the main materials (steel cylindrical bars) are newly inputted during the first process called the cutting process, the costs of the main materials should be excluded in order to compare the costs of negative products generated in the different processes fairly.

It is apparent the costs of the negative products generated in the MC process are much greater than that for the other processes.

4 INNOVATION PLAN AND THE TO-BE MODEL

The above analysis results are shown for Company A. By examining possible methods of improvement, Company A established a process innovation plan that involved taking advantage of the speed of the forging process to make the surrounding holes, called D holes, instead of drilling the holes during the MC process. The process-changing innovation is shown in Figure 8.

If the innovation plan is successful, the time of the MC process will be reduced significantly, while the forging process time will almost not be changed, as shown in Table 6.

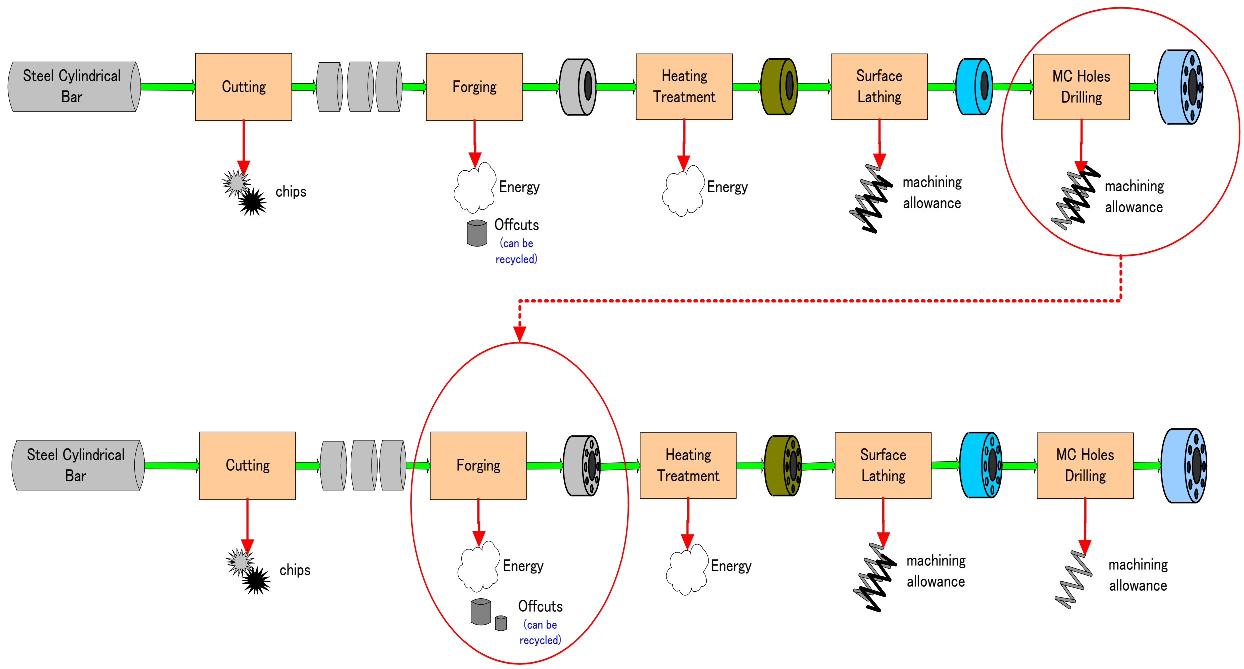

Figure 8: Diagram of the process-changing innovation

Table 6: MC process time in the AS-IS model and the TO-BE model (Unit: hours)

Product Type		M1	M2	L1	L2
AS-IS Model	**Forging Process**	1.1	1.2	1.54	1.6
	MC Process	9.54	8	17.62	14.46
TO-BE Model	**Forging Process**	1.21	1.24	1.69	1.75
	MC Process	4.03	1.3	1.1	0.67

Because the MC processing lead time should be significantly reduced, a detailed plan can be made based on the real orders during the forging process, which may lead to a reduction in WIP stock. Figure 9 shows the details of the changed business flow.

To test the effectiveness of this innovation plan, a TO-BE simulation model was constructed, as shown in Figure 10.

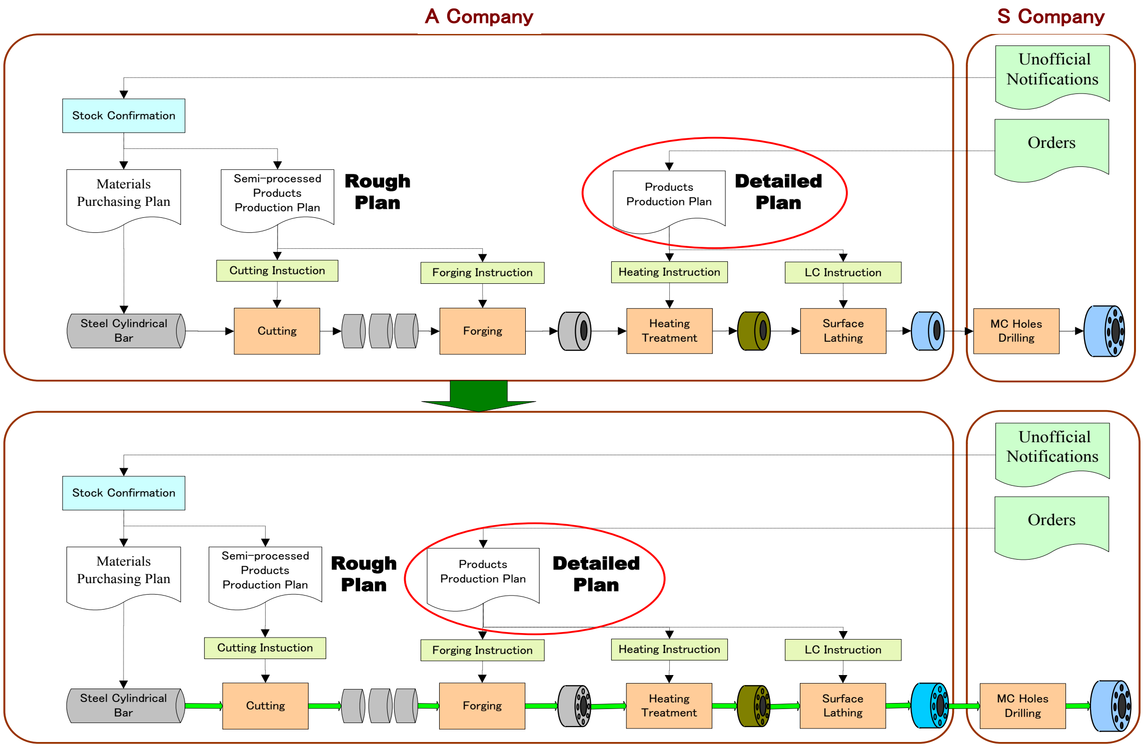

Figure 9: Business flows of the AS-IS and TO-BE models

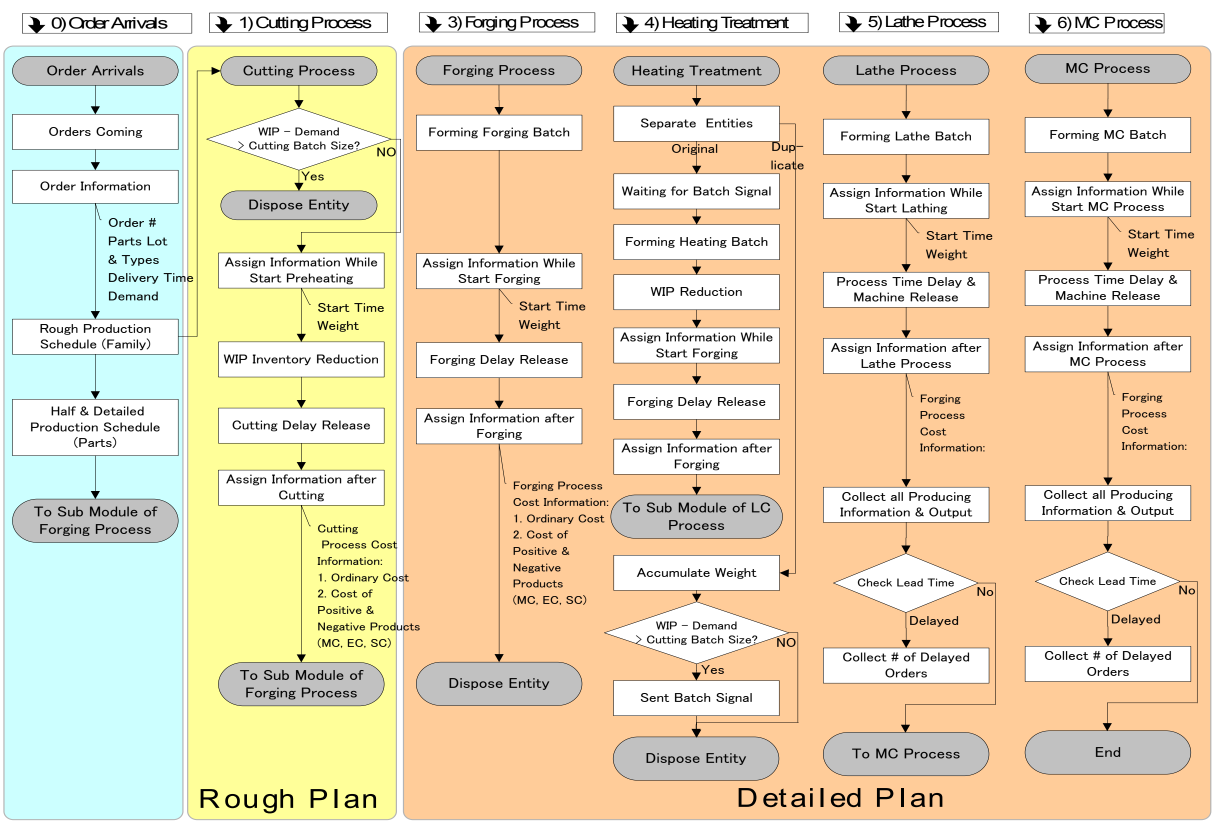

Figure 10: The logic of the TO-BE model

Figure 11, Figure 12, and Table 7 show the execution results of the TO-BE model. Compared with the results of the AS-IS model, the values for environmental performance and economic performance were balanced in the TO-BE model. Even though the production lead time was shortened and the delayed orders were decreased more, the WIP stock problem was improved remarkably as well. On the other hand, compared with the AS-IS model, negative products cost was reduced, that is, the environmental burden was improved.

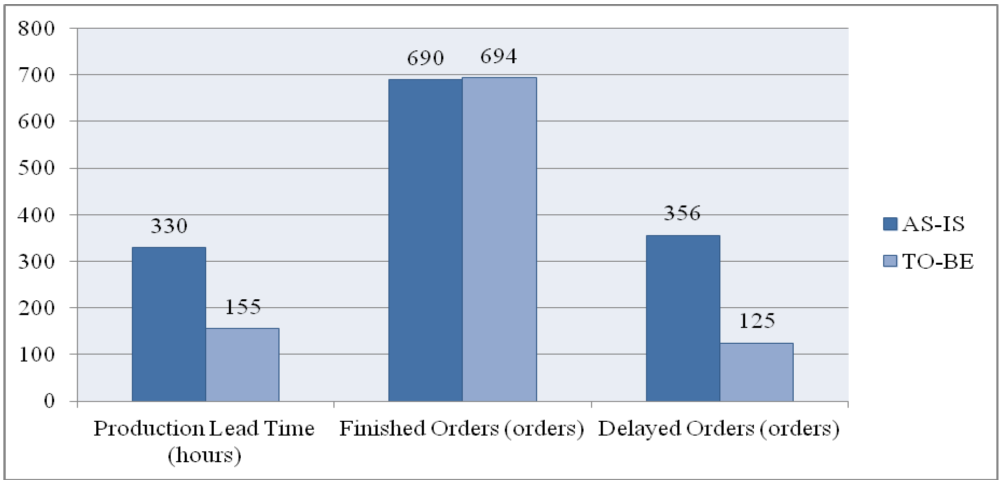

Figure 11: Simulation of the results for economic performance

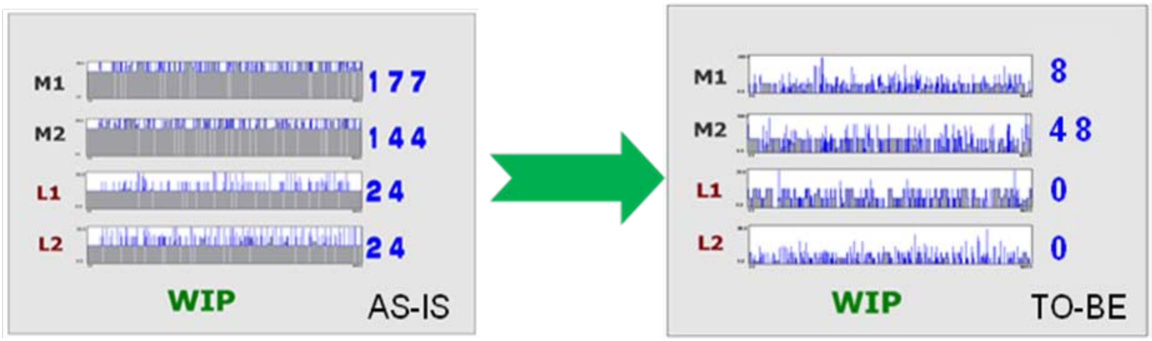

Figure 12: WIP improvement

Table 7: Simulation of the results for MFCA (environmental performance) (Unit: thousand JPY).

Simulation Models	Positive Products Cost	Negative Products Cost	Total Cost	Negative Products Cost Rate
AS-IS	43,398	**4,862**	48,259	**10%**
TO-BE	41,352	**3,908**	45,260	**8.6%**

5 CONCLUSIONS

In this study, the effectiveness of the MFCA in-process management technique was confirmed through the construction of a simulation model using the MFCA concept. Through the process innovation of changing the hole-cutting method of a part from the MC process to the forging process, the parent company can achieve a remarkable reduction in its machining allowance, leading to significant environmental improvement. For the designated company, in which the forging process is mainly accomplished, both revenue and profits will be increased by strengthening the forging process and increasing the added value of the processed products. Furthermore, the semi-processed product inventory will be significantly reduced by the precise production plan, and the production lead time of the entire supply chain will be shortened. These changes will have environmental and economic benefits for both companies.

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