Ceramics Process Improvement with Material Flow Cost Accounting

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Abstract— **Manufacturing enterprises nowadays are operating in a more competitive environment due to various factors, such as fast-changing markets, more competitors, and more regulators. To remain competitive, they must find ways to increase their production efficiency. Decisions regarding process improvement must be made with sufficient supporting information. Material flow cost accounting (MFCA) has gained more attention due to the growing concern about the effects of the business's activities on environment. MFCA provides detailed information regarding production waste, which conventional management accounting fails to do. The MFCA helps to improve decision-making skills regarding waste-reduction activities to be more focused and accurate. The MFCA is relatively new since its first international standard (ISO14025) was published in 2011. Most of the research in MFCA has so far focused on the technical side of MFCA or on investigating cost structure; the use of MFCA to solve practical problems is very rare. This paper, therefore, presents a more complete picture of the implementation of MFCA, starting from data collection and MFCA calculation to waste-reduction activities. A case study of ceramics production was used to demonstrate the application of MFCA. The result of the case study confirms that MFCA is a practical tool that helps decision makers to make better decisions, which would lead to sustainable cost reduction in actual business environment.**

Keywords—material flow cost accounting, ceramics production, cost reduction, process improvement

I. INTRODUCTION

The manufacturing industry is now operating in a more challenging environment than in the past. Global competition is constantly getting more intense. Globalization, coupled with advanced telecommunication technology, allows companies to have their products made anywhere in the world. With more competitors and more product choices, the market now belongs to the customer. Customer needs are changing faster, which results in shorter life for product profitability. To stay competitive, strategies for addressing these pressures must be developed. Manufacturing process improvement is one of the strategies adopted by many firms. Decisions regarding manufacturing process improvement should be made with sufficient supporting information. Moreover, concern over environmental issues such as global warming, resource replenishment, and energy prices has increased rapidly in the past decades. Industries are not only required by laws and regulations to reduce their impact on the environment but also required to handle increasing pressure from stakeholders to evaluate the environmental impact of the business more accurately. As such, there is an apparent need for techniques that take environmental impact into account in order that it helps managers to make better decisions.

Typically, conventional cost accounting is designed mainly to calculate production cost for the purpose of determining the product selling price. However, the conventional method fails to consider the environmental aspect because the environmental cost is usually considered as an overhead and, therefore, as "hidden" in the cost structure [1]. Material flow cost accounting (MFCA), on the other hand, is a managerial accounting procedure designed specifically to capture the cost of waste generated during the production. In MFCA, output from every production process is classified into either a positive product (a product that the company sells to its customers) or a negative product (production waste). With the realization that waste is generated in every process, the cost is made to be proportionate to the negative product as well as the positive product. Since MFCA provides in-depth analysis of production waste in terms of both the costs of waste and their impact, the company can use this MFCA information to make better decisions regarding waste reduction.

There have been reports of MFCA applications in industries [2-4]. However, most of the researches apply MFCA only to study cost and its structure. Very few cases actually use the MFCA information to conduct waste reduction activities. Traditional studies on MFCA emphasize its technical side, such as the difference of MFCA from other management accounting methods[5]. Previous works on MFCA focused on describing the characteristics of MFCA but did not aim to solve practical problems[6]. This paper, therefore, attempts to fill this gap by providing a more complete picture of MFCA implementation, right from data collection, cost calculation, and allocation through process improvement activities. A case study from ceramics industry was used to demonstrate MFCA application.

Ceramics industry is one of the important industries in the northern part of Thailand. It has major roles to play in both tourism and export markets. Currently, there are more than 200 ceramics factories in Lampang Province. This is because raw materials such as clays, feldspar, and quartz can be found in this area. The ceramics industry not only contributes to Thailand's

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economy in terms of export but also provides employment to local people. The majority of ceramics producers in this region are small scale and medium scale. Factors that are currently affecting Thai's ceramics factories include global competition, appreciation of baht, and the increase in the minimum wage rate. In order to survive and gain competitiveness, ceramics producers have the immediate need to reduce their production cost. Since MFCA helps to provide information on the accurate cost, the decision makers can use the MFCA method to direct their attention to the right place.

The case study company considered in this paper is a ceramics producer in Lampang Province who specializes in tableware products. Approximately eighty percent of the company's products are made to order. Therefore, the production processes are not standardized and are labor intensive. The problems found in the production are, for example, excessive use of raw materials as well as ineffective and non-standardized working methods. The ceramic mug was chosen for the MFCA calculations as it is the main product of the company and it has a steady demand and contributes to more than 50% of the entire production. Approximately, 234,000 mugs are produced per month. Ceramic mug production consists of 16 processes, which include mud preparation one, mud preparation two, rolling, edge forming, handle attachment, heating, cleaning, biscuit firing, quality control, glazing, glaze firing, grading one, decal attachment, decal firing, grading two, and packing.

According to the preliminary analysis, approximately 31.47 percent by weight of clay becomes waste during the production of the body of the mug and an additional 36.91 percent by weight is lost during the fabrication of the handle. However, with the lengthy production line of 16 processes, it is difficult to track which process contributes the highest to these losses. As a result, this study aims to apply the MFCA technique to analyze the production cost structure for the purpose of process improvement. With the MFCA cost structure, the critical process can be identified. After that, the appropriate process improvement techniques are implemented.

II. THEORIES

A. *Manufacturing process improvement*

Approaches to process improvement have been developed over time since the industrial revolution era. In the beginning, process improvement focused on designing appropriate tools and methods for performing each job. Then came the mass production era where product and production process were both standardized and automation was used to replace craftsmanship. However, standardized products are not able to satisfy the customer well, so the aspect of quality was emphasized. In the quality era, efficiency in production focused on statistical process control and Deming's cycle (Plan-Do-Check-Act). Later, after World War II, Toyota Motor Corporation applied the concept of production in smaller quantities in order to better meet the specific needs of the customer. This concept formed the foundation for "lean manufacturing."

In the course of time, popular tools and techniques for process improvement have been proposed, beginning with the most basic tools, the "seven basic tools of quality," which include the check sheet, graphs, cause and effect diagram, histogram, Pareto diagram, scatter diagram, and control chart. Another well-known set of tools for process improvement is the "Six Sigma", introduced by Motorola, Inc. in the mid-1980s. Six Sigma is an organized method to reduce process variation [7]. The objective of Six Sigma is to reduce defect to only 3.5 defects per million. In ceramics production, this objective is hard, or almost impossible, to achieve as the process is subject to variations from various sources including material, method, and labor. "Lean manufacturing" is the latest concept of process improvement for the rapidly changing and highly competitive market [8].

All the improvement packages described above have been reported to have direct links to the firm's performance. However, most of the improvement programs incur a cost, and applying improvement programs to all the processes is not possible, especially in small enterprises where budget is constrained. Decisions related to the most suitable improvement program have to be made with sufficient supporting information as, as in [9], the initial choices made regarding the improvement method affect later ones. Material Flow Cost Accounting (MFCA) is a tool that can be used to provide such information. The concept of MFCA is described in the following section.

B. *Fundamental principle of MFCA*

Material Flow Cost Accounting (MFCA) is an environmental management accounting technique that quantifies the flow of material in the production process in terms of both the physical units, such as mass, and the costs associated. It has been identified as one of the most promising methods in environmental management accounting [10, 11]. In contrast to the traditional system which automatically includes the cost of waste in the product cost, MFCA observes waste as a kind of product, the so-called negative product, with its associated cost. Therefore, MFCA helps in making decisions about waste reduction by providing monetary information regarding the various benefits of waste reduction[12].

MFCA was first developed in Germany in the late 1990s. It has been adopted by many Japanese companies as promoted by the Japanese Ministry of Economy, Trade and Industry (METI) [13]. The guidelines for implementing MFCA were published in 2007 by METI, and the first edition of the international standards for MFCA was published by ISO (ISO 14051) in 2011.

MFCA traces the quantity of material flow in the manufacturing process back to the point where material losses (waste) are generated. Output from every process is classified as either a positive product (a product that the company will sell to its customers) or a negative product (material losses). By realizing that there are two types of output, the costs of materials together with other conversion costs such as labor cost and depreciation are allocated not only to the positive product but also to the negative product. MFCA, therefore, unlike conventional costing, provides detailed cost information regarding the wastes involved.

ISO 14051 (2011) identifies four elements of MFCA, which are quantity center, material balance, cost calculation, and material flow model. Quantity center is an “object of interest” for which inputs and outputs are quantified. Quantity center comes in many forms such as the production process, group of processes, storage, and shipping point. For example, Reference [2] grouped the production process of making ceramic tiles into the quantity center, whereas Reference [14] used the individual process of producing toothbrush as the quantity center. After quantity centers are identified, the quantity of materials, input, and output to every quantity center are recorded. The next step is to construct the material balance table. The concept of material balance is based on the theory that the physical quantity of the input materials must be equal to the quantity of the output materials. Material balance is used for every quantity center to identify whether the data collection of any of the materials is “missing.” Thereafter, cost calculation is performed to directly trace the energy cost, system cost, and waste management cost to positive and negative products, based on the quantity. The cost that cannot be directly traced back will have to be allocated to the positive and negative product using the appropriate driver. For example, Reference [2] used the ratio of the material content, whereas Reference [15] used the value ratio for the allocation. As the final step, material flow model is constructed. The material flow model is a tool for the visualization of material flow from one quantity center to another. The material flow model is used not just in isolation in MFCA, but also in conjunction with other techniques (see, for example, [16]).

III. RESEARCH METHODOLOGY

The research methodology is divided into two phases. The first phase, the MFCA phase, focuses on the MFCA calculation. The result from this phase is the cost structure which is used in the second phase, process improvement.

A. MFCA phase

First of all, data related to material, energy, and system were collected in order to calculate the costs for each quantity center. For the calculation of the material cost, the type of the materials, their quantity, and unit cost were collected for each quantity center. In order to calculate the energy cost for each quantity center, the type and number of the machines, their kilowatt hour, and machine hour were collected. System cost is the cost incurred from in-house handling activities, such as labor cost and depreciation. However, in this case study, equipment, machine, and building were fully depreciated. Therefore, only labor cost was considered. In order to calculate the labor cost, the number of workers, standard time, and wage rate per hour for each quantity center were collected.

Next, the material flow model was drawn to illustrate the flow of materials. In this diagram, the materials are classified into main material, sub material, and aux material. Main material is the major material that is included in the finished product, whereas sub material is the additional material that is added to the main material. Both main and sub materials become part of the finished product, whereas aux material — which is the material used during production — does not become a part of the final product (an example for aux material would be water used in a cleaning process). Additionally, in the material flow model, the weight quantities of both the input and the output (both positive and negative products) are shown.

Material balance tables were constructed for each quantity center to calculate the percentages of the output that became positive product or negative product. In this work, these percentages were calculated based on the dollar value of the materials that advanced to the next process and the dollar value of the materials that became waste. The type and quantity of the input and output materials from the material flow model were input into the material balance table. The costs of the input and the output materials were calculated by multiplying their quantity with their unit cost. Thereafter, the value percentages of the negative and positive products were calculated from the proportion of the cost, that is, the value percentage of the negative product = the cost of the negative product/total cost.

Next, cost calculation was performed. The percentages of the negative and positive products obtained previously were used to separate the energy cost and the system cost into positive product and negative product. The costs from all the quantity centers were summed to produce the cost structure to be used as input in the improvement phase.

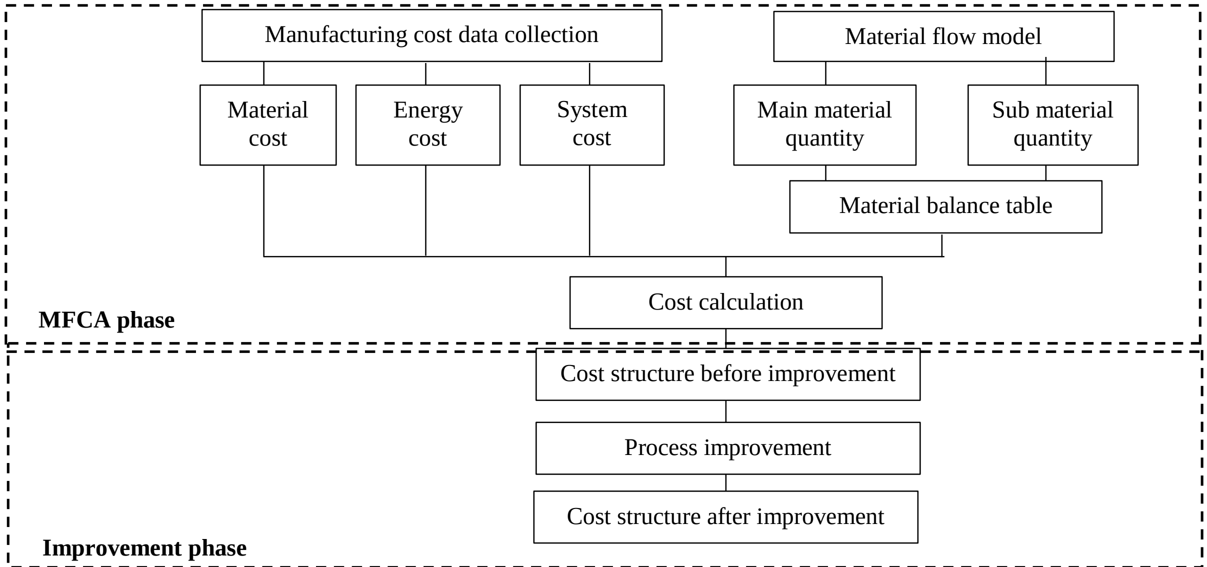


Fig. 1. The research methodology.

B. *Improvement phase*

In the improvement phase, the cost structure before the improvement procedure was analyzed in order to pinpoint the quantity center that had high negative product cost. The cost structure also provides information on which type of cost is the highest. Process improvement tools were applied to find a new working method. The proposed method was put through trials, and the cost structure after the improvement procedure was calculated.

IV. RESULTS

Figure 2 presents a material flow model of ceramic mug production. The quantity of materials recorded in this material flow model is for a one-day production (approximately 9,000 mugs). Mug production starts with two stages of mud preparation where mud, prepared in another factory, is mixed with water to make it softer. Then the mud goes into the rolling and edge-forming process to obtain the shape of a mug. After the mug is properly formed, the handle is attached and the mug is passed through the heating process in order to stabilize its shape. The next process is to clean the mug with water. After the cleaning step, the mug passes through the biscuit-firing process. In the biscuit-firing process, high heat is applied to change the texture of the mug into ceramic. It is then checked for quality at the quality control station. The mug that passes the quality control station successfully then moves on to the glazing process, where it is dipped in the glazing solution, after which heat is applied again in the glaze-firing step. In the next process, grading, the mug is classified into different grades according to its quality. Subsequently, decal sheets which contain pictures are attached to the mug, and it is fired in the decal-firing process. The grading step is repeated again, after which the mug is ready for packing as the final step.

After the material flow modeling step, the next step is the material balance. In this work, material balance was calculated for each of the 16 processes. Table 1 presents an example of a material balance table for the rolling process.

Table 1. Material Balance Table of Rolling Process

Material Balance Table (Rolling Process)					
Input: Material used		Output: Waste (negative product)		Output: Company Products (positive product)	
Materials	Quantity (kg)	Waste	Quantity (kg)	Company product	Quantity (kg)
Mud	3,861.00	Mud	1,215.00	Mud	2,646.00
Water	24.00	Water	7.65	Water	16.35
Total (kg)	3,885.00	Total (kg)	1,222.68	Total (kg)	2,662.35
Value percentage	100%	Value percentage	31.47%	Value percentage	68.53%
Cost of input material		Cost of wasted material		Cost of company product	
Total (THB)	38,610.00	Total (THB)	12,150.00	Total (THB)	26,460.00

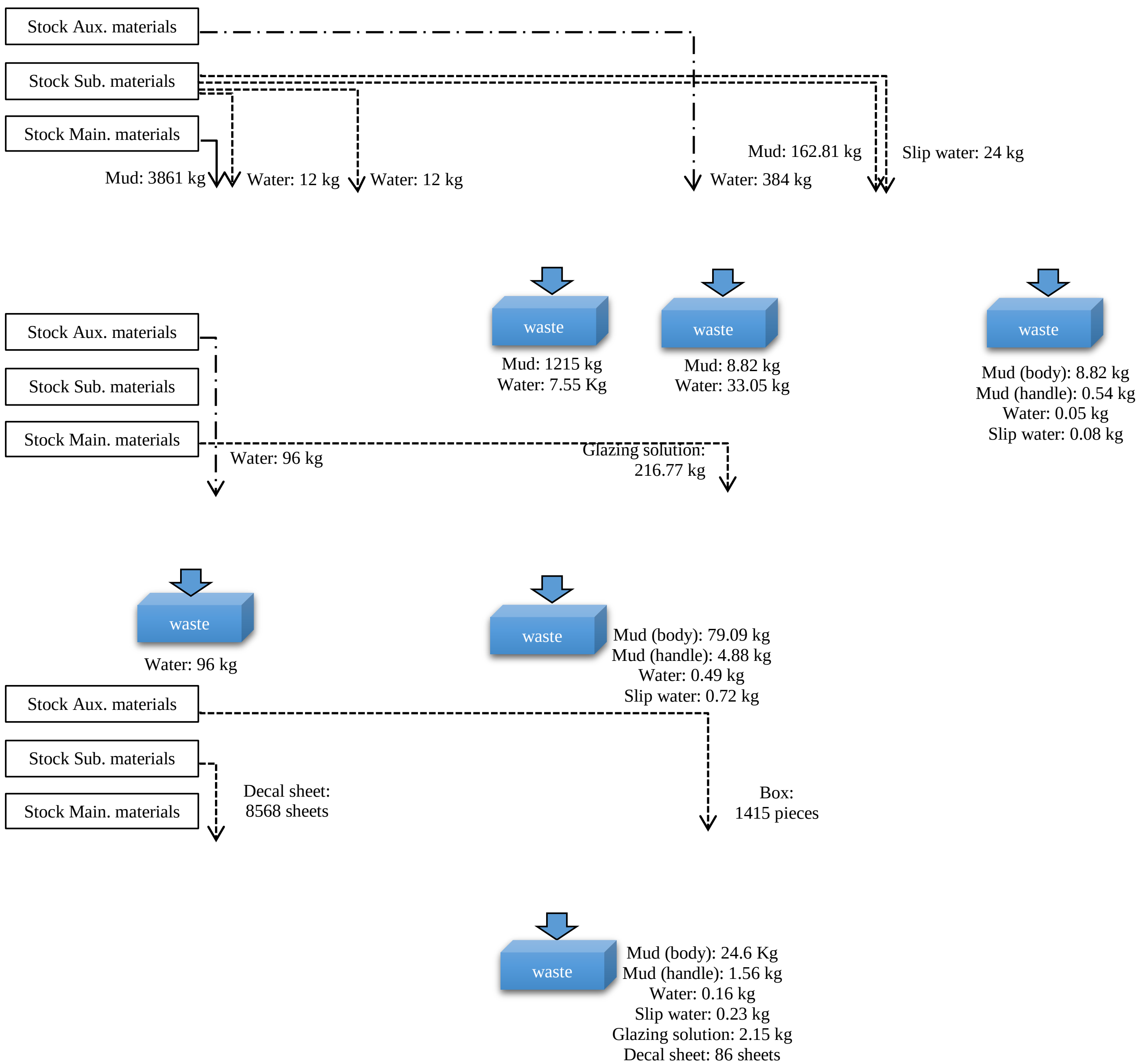


Fig. 2. The mug production material flow model.

There are two types of input materials in the rolling process, and they are mud and water. Two types of outputs, that is, positive products and negative products, are considered. In this work, the materials were balanced using the cost of materials which was calculated by multiplying the material quantity with its unit cost. Then, the value percentage was calculated from the proportion of the cost, that is, the value percentage of the negative product = the cost of the negative product/total cost = 12,150/26,460 = 31.47%, and the value percentage of the positive product = the cost of the positive product/total cost = 26,460/38,610 = 68.53%. A total of 16 material balance tables were constructed for all the 16 processes.

The next process is cost calculation. The material cost can be proportioned directly to the positive or the negative product based on the quantity. The system cost and the labor cost, on the other hand, are available only for an entire quantity center. As a result, they have to be allocated to the positive product and the negative product using the value percentages obtained from the previous step.

Figure 3 is an example of cost allocation in the rolling process. Rolling is not the first stage in the production process; hence, there is bound to be some attached cost from the previous processes. Hence, the total cost to be allocated was calculated by summing the costs from the previous processes and the cost of the new input. The total cost was allocated to the positive product and the negative product with the proportions of 68.53% and 31.47%, respectively, using the data presented in Table 1.

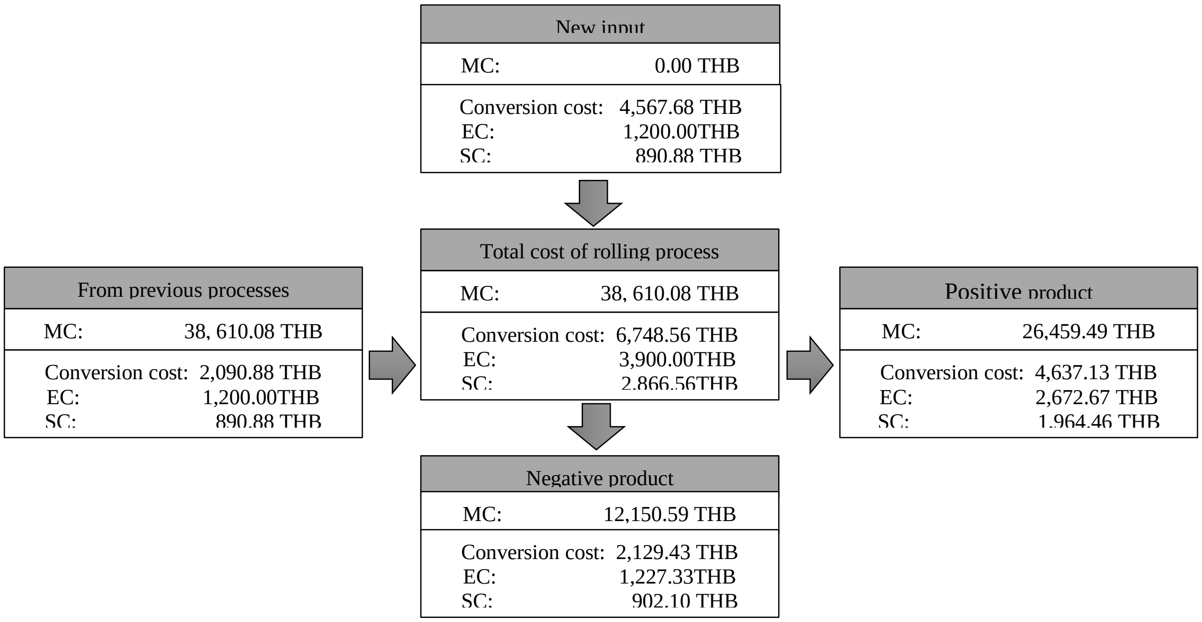


Figure 3. The MFCA cost calculation for the rolling process.

Cost item	Mud prep 1	Mud prep 2	Rolling	Edge forming
New input total cost	39,927.84	857.04	4,676.00	2,245.47
MC	38,652.00	42.00	0.00	1,344.00
SC	600.00	600.00	2,700.00	900.00
EC	675.84	215.04	1,975.68	1.47
Total cost carried over from	0.00	39,927.84	40,784.88	31,154.37
MC	0.00	38,652.00	38,694.00	26,517.21
SC	0.00	600.00	1,200.00	2,672.69
EC	0.00	675.84	890.88	1,964.47
Process input total cost	39,927.84	40,784.88	45,460.88	33,400
MC	38,652.00	38,694.00	38,694.00	27,861.21
SC	600.00	1,200.00	3,900.00	3,572.69
EC	675.84	890.88	2,866.56	1,965.94
Positive product percentage	100%	100%	68.53%	94.86%
Negative product percentage	0%	0%	31.47%	5.14%
Positive product total cost	39,927.84	40,784.88	31,154.37	31,683.13
MC	38,652.00	38,694.00	26,517.21	26,428.84
SC	600.00	1,200.00	2,672.69	3,389.02
EC	675.84	890.88	1,964.47	1,864.87
Negative product total cost	0.00	0.00	14,306.19	1,717.12
MC	0.00	0.00	12,176.79	1,432.38
SC	0.00	0.00	1,227.31	183.68
EC	0.00	0.00	902.09	101.07

Figure 4. The material flow chart of quantity centers 1–4.

Cost calculation was performed in the same way for all the 16 quantity centers. Figure 4 is an example of the material flow chart of the first four quantity centers. For the first quantity center (the mud preparation one), the total cost carried over equals to zero. The process input total cost is the summation of the new input cost and the carried-over cost. The process input total cost was allocated to the positive product and the negative product using the value percentages calculated in the material balance step. The total cost of the positive product in the first quantity center becomes the total cost carried over to the next quantity center, and the calculation repeats in the same manner for the rest of the quantity centers.

After the completion of cost calculation, the total costs of the positive products and the negative products from every cost center were added up. Figure 5 presents a summary of the MFCA results. It shows the percentages of the total input, both positive and negative, in terms of the system cost, the energy cost, and the material cost. It can be concluded that out of the 100% value of the input, 90.05% becomes the product to be sold to the customer, while 9.95% becomes waste. Material cost makes up the biggest part in the mug cost structure.

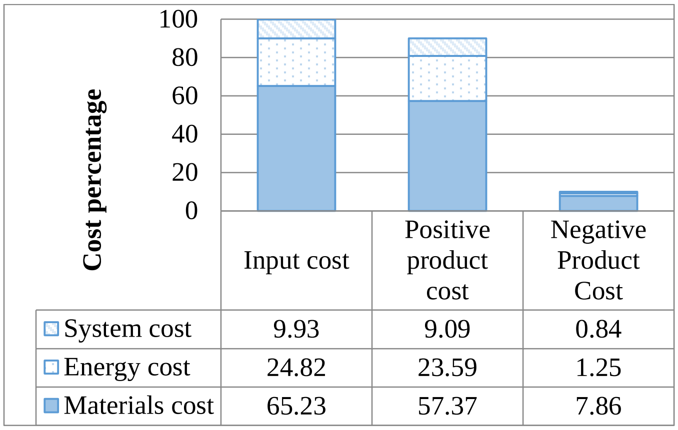


Fig. 4. The cost structure before the improvement process.

One of the advantages of MFCA is that it provides detailed information regarding wastage; as a consequence, decision makers are able to direct their improvement efforts to the right place. Figure 6 shows the top seven quantity centers that have the highest costs due to material loss. The item that has the highest value for loss is material cost from the rolling process.

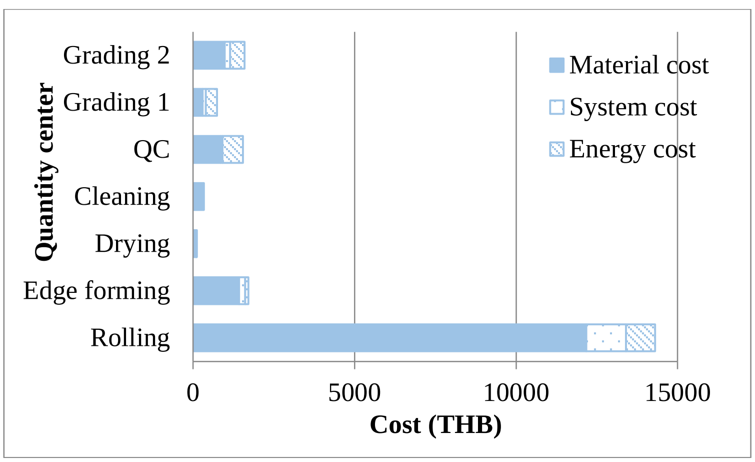


Fig. 5. The material cost, system cost, and energy cost of the negative products for the top seven quantity centers.

With a view to reducing the amount of material waste in the rolling process (Figure 7a), the working procedure was reviewed. It was estimated that to make one mug which has a final weight of approximately 294 grams, it required more than 294 grams of mud to be placed into the rolling machine in order that the mug takes form properly. According to the current bill of materials, 429 grams of mud is fed into the rolling machine, and the excessive material weight of approximately 135 grams becomes the material loss (Figure 7b). This quantity, that is, 31.47% of the extra material, is considered too much wastage. The amount of input material can be reduced, but only to some extent. If the quantity of input material is reduced too much, the mug might fail during either the biscuit-firing or the glaze-firing process. Experiments were conducted to find out the maximum amount of mud that can be reduced without compromising the quality of the finished product. The results of these experiments are presented in Table 2.

a) Rolling process b) Material loss from rolling process

Fig.6. The rolling process quantity center.

The experimental results demonstrate that the extra mud can be reduced by up to 19%, or that at least 349.86 grams is required; otherwise, the mugs will start to fail in the glaze-firing process. The bills of the materials were, therefore, updated accordingly; thus, instead of preparing 429 grams per mug, only 349.86 grams of mud was required, which is a reduction by 18.45%.

Table 2. Quality Inspection Sheet of Experiments to Reduce Percentage of Extra Mud

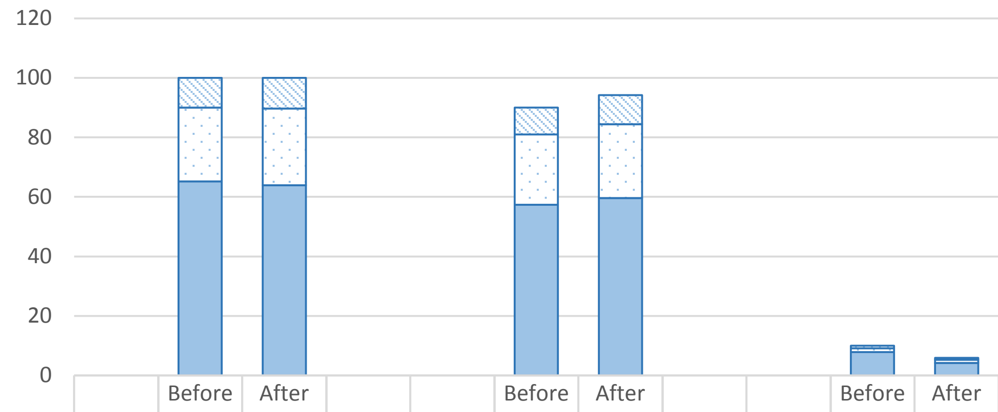
No.	% of extra mud	Weight (g)	Biscuit Firing										Glaze Firing									
			1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	25%	367.50	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	23%	361.74	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	21%	355.74	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	19%	349.86	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	17%	343.98	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✗	✓	✗	✗	✗	✗

Note: "✓" = product passes quality inspection; "✗" = product does not pass quality inspection

Apart from updating the bills of the materials, other activities were also set up and developed, such as a new standard working procedure. A standard working procedure acts as a guideline to workers. It helps them to perform the work easier and to reduce mistakes. Check sheets were also introduced so that the workers could inspect the work properly to prevent the products from becoming defective. After all the improvements were implemented, the data were collected again for the MFCA calculation. The results are illustrated in Figure 8.

Figure 8 shows that after the improvements, the cost of the material input was reduced from 65.23% to 63.86% (i.e., a 1.37% reduction). As the improvements were focused on reducing the material cost, the system and energy cost inputs were not significantly different. On the output side, the material cost was observed to become a positive product at a higher percentage after the improvements (from 57.37% to 59.62%). At the same time, it was observed that less of materials had become negative product as indicated by the reduction in the percentage of material waste, from 7.86% to 4.24%. This can be converted to a negative cost reduction of 10,604.28 baht per 9,000 mugs.

Although this case study demonstrates very promising results, there remain several topics still worthy of discussion. First of all, the driver used for the material balance can significantly change the result. Selecting an inappropriate driver will result in misleading conclusion. For example, the typical driver used to balance materials is chosen by weight, but in the case that the material used is cheap but heavy, the weight balance will not make much sense. In edge forming, for example, this process consumed a lot of water (approximately 400 kilograms per batch), and a considerable volume of water was wasted in this process. As the cost of water is very cheap in comparison with the cost of mud, allocation by weight in this case will result in over-allocation to the negative product. So, instead of using weight for the allocation, this research allocated the cost based on the value of the material whose waste had to be reduced.



	Input cost		Positive product cost		Negative product cost	
	Before	After	Before	After	Before	After
System cost	9.93	10.33	9.09	9.78	0.84	0.55
Energy cost	24.82	25.82	23.59	24.75	1.25	1.07
Materials cost	65.23	63.86	57.37	59.62	7.86	4.24

Fig.7. The cost structure of the BAU mug before improvements vs. after improvements.

Secondly, MFCA provides the costing detail of every quantity center, which allows the decision maker to decide on and select not only the quantity center to be improved first but also the type of cost that needs immediate attention. In this work, a quantity center is defined as an individual production process. As the number of processes is 16, data collection is very difficult. In practice, individual processes can be grouped together to form a quantity center. This will help to reduce the amount of data to be collected tremendously.

Finally, after the improvements were made to the process, MFCA should be calculated again with the new data. This is to ensure that the improvements made really resulted in actual reduction in the total cost. As in some cases, reducing the cost in one category affects the costs in the other categories. In this case study, even though the improvements were focused on reducing the amount of material loss, it can be seen that the system cost and the energy cost were also reduced.

V. CONCLUSION

This research elaborates MFCA implementation in a complete cycle, right from data collection and cost calculation to how to use this information to set up waste reduction activities. MFCA offers detailed cost analysis regarding the exact quantity of material loss that has occurred in the actual production, something which conventional cost management methods fail to provide. With the accurate cost information available regarding the material loss, decisions regarding waste-reduction activities can be made faster and more accurately. Consequently, waste-reduction activities can be tackled from the right angle.

There are some concerns, however, when implementing MFCA. Firstly, the quality of the MFCA results would be as good and accurate as the quality of the input data. Data collection has to be conducted carefully to ensure the validity of the result. Secondly, the driver used in the allocation process has to be carefully selected. Choosing inappropriate drivers might result in misleading or wrong conclusions. Finally, implementing MFCA is not an easy task as large amounts of data have to be collected. Nevertheless, this case has proved categorically that MFCA is a powerful tool that can lead to practical solutions for an organization. The company, therefore, gains benefits not only from the reduction in the environmental impact but also directly and immediately from the reduction in costs caused by wastage.

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