A STUDY OF THE COST PERFORMANCE ANALYSIS OF A PRIVATE FIRM DEPLOYED 3D PRINTING TECHNOLOGY : AN ACTUAL CASE OF A WIRE MANUFACTURING COMPANY

by

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Abstract

To grasp the cost structure is an aspect of the competitiveness of a company's strength. However, the research for studying a method for discussing costs is not insufficient. As a result, this study attempts to discuss and consider the cost structure applied to a real wire frame company. For the purpose, it tries to compare a typical manufacturing process with a situation in which 3D printing technology is introduced. Concretely, the IDEF0 method is introduced to clarify the process, and the cost-matrix method is used to calculate costs related to the IDEF0. This study also clarified a future issues related to the introduction of 3D printing technology. Through these analyses, this study provided an understanding of the cost structure for each activity in the real company, a discussion of a typical manufacturing process and the introduction of the 3D printing process and clarifying future discussions regarding the introduction of 3D printing technology.

1. Introduction

In a competitive manufacturing industry, understanding the cost structure is very important because price is typically influenced by cost. Moreover, sales and profits are affected by changes in costs, depending on the setting, structure, and establishment. Various methods exist to clarify the cost structure, such as the cost accounting method, cost–volume–profit (CVP) analysis, activity-based cost (ABC), activity-based management (ABM). The ABC method, for example, traces costs. Further, an indirect cost is divided into each activity depending on the time taken for the activity. Consequently, the method comprehends real activity cost. However, it is not enough that the ABC method uses only an activity's time because various activity indicators exist, such as number of laborers, equipment, and operating time. To obtain detailed information, realizing a "process" in a manufacturing situation and discussing the cost and profit structure of a detailed process are useful.

Three-dimensional (3D) printing technology has arrived and is changing the philosophy of "processing." This technology allows a 3D replication of a solid object and can virtually shape any item from a digital graphics file. The printed product is made from a powder or resin. The range of applications for this manufacturing technology is extensive and includes the automobile industry, consumer electronics parts, medical organs, and architectural models (Leukers et al., 2005, Silva et al., 2008, Parthasarathy et al., 2011).

Considering former two topics, this study attempts to focus on 3D printing technology and its influence on manufacturing industries. It specifically discusses the impact of 3D printing technology applied to manufacturing companies on their cost, time, and activities. To answer this question, a cost structure is developed using the integrated definition for function modeling (IDEF0) process modeling method. The cost calculation is also considered using the cost-matrix method. Through these analyses, problems related to the target manufacturing company are clarified, and the discussions indicate the results of introducing 3D printing technology.

2. Previous studies and this study's approach

Numerous studies focused on cost management. Historically, ABC and ABM were applied to numerous companies. ABC is a management technique to achieve both a service improvement and a cost reduction from the optimal use of resources through a separate analysis of activity units. ABM includes the strategic concept into ABC. ABM provides a numerical basis, so it helps to company's decision making in the scene of product strategy, examination of prices and transactions, and improvement plans for waste work and time reductions. These conventional ABC and ABM methods are able to use a variety of solutions to understand costs. However, they do not provide clear definitions about activities. In addition, the calculation step for each cost is not shown (Brimson, James and Robin Fraser, 1991). Therefore, this study clarifies each activity's elements through the IDEF0 process modeling method (David A, et. al., 1987).

The IDEF0 method is useful for distinguishing the activities through a drawing base. They have many researches attention to the cost management with the IDEF0 method. Qian and Ben-Arieh (2008), for example, studied to evaluate the cost for machined parts. For that matter, the IDEF0 model used to clear the activities along to the ABC moving, working time, operating time and design time. They gave some example with the linkage between ABC and the cost to calculate standard and suggest the cost computation form. Bargelis and Stasišk (2008) are proposed a new intelligent support tool for making the best decision between available product and process alternatives. IDEF0 has been applied to estimate and increase the process capability at the early product and process design stage. From their simulation, they said that IDEF0 model and mathematical form reduce the risk of implementing new products, processes and operations. They show that capability and manufacturing cost analysis helps to determine the ability for manufacturing between tolerance limits and engineering specifications. Numerous studies paid attention to cost management using the IDEF0 method and the IDEF0 method is useful for distinguishing activities through a figure base, as illustrated in Figure 4. However, these studies focus on only "one" activity typically in the manufacturing process, which has numerous processes that interrelate among the activities. Consequently, each cost related to the activities' interface, which manages the input and output of the activities, constraints, and time, needs to be discussed and clarified. Further, these studies did not focus on the possibility of 3D printing.

In contrast, numerous studies provided approaches that focused on 3D printing. They were dedicated to the possibility of printing (Foroozmehr and KovacevicR, 2009), focused on efficient ways to print (Zhang and Khoshnevis, 2013), and discussed the cost effect (Kenny, 2013). Previous studies failed to identify the influence of 3D printing technology's activities on cost, the management process, and the value added. Therefore, Nakamura et al. (2014) examined the possibility of 3D printers in terms of manufacturing processes, product inventory, and product yield. To clarify the process, they analyzed process flows using IDEF0 and calculated a cost structure. Their study attempted to connect IDEF0 and the cost structure. However, the object of IDEF0 is a hypothetical company, and discussing the application of 3D printing technology is difficult.

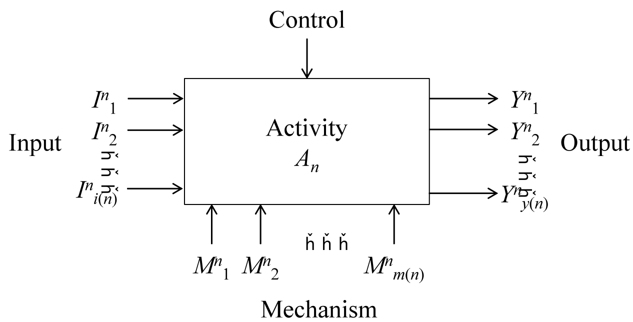
Consequently, this study attempts to compare a typical manufacturing process in a real wire frame company with a situation in which 3D printing technology is introduced. The IDEF0 method is introduced to clarify the process, and the cost-matrix method is used to calculate costs related to the IDEF0. Through these analyses, the cost structure must be clear in the process flow. Moreover, future prospects regarding situations in which a real manufacturing company introduces 3D printing technology are discussed.

3. Using the IDEF0 and the cost calculating model

3.1 Using the IDEF0

To clarify the process activities involved with human resources, products, and equipment, this study introduces the concept of the IDEF0 for the manufacturing process model (Figure 1). The box in Figure 1 indicates an activity, such as "manufacturing process" or "delivery." The arrows indicate the flow of materials, the design file, the product, and so on. The inputs enter from the left side of the box ($I^n{}_{i(n)}$) and the outputs exit from the right side of the box ($Y^n{}_{y(n)}$). Inputs are transformed into outputs through the activity. Outputs created include data or objects produced by the activity. Arrows entering the box from the top represent controls (C) that specify the conditions required for the activity to produce correct outputs. Arrows connected to the bottom of the box represent mechanisms ($M^n{}_{m(n)}$). Upward pointing arrows identify support for the execution of the activity. Activities are linked through the input and output arrows, and a generic term of these four arrows is called an "ICOM." The activity also clarifies the hierarchical characteristic and the nested structure of new activities, which explains the details of the activity.

Figure 1: Activity of IDEF0



After clearing the activities through the IDEF0 method, each activity's cost calculates by using the cost-matrix method. Its method composes from the labor cost and time, raw materials total cost, and the equipment total costs. In this approach, each activity's cost is clearing through the calculation.

3.2 The cost-matrix model

The cost-matrix method is formed as follows:

$$\begin{aligned} C^n &= \left[c(Y_1^n) \;\; c(Y_2^n) \; \cdots \; c(Y^n_{y(n)}) \right]^T \\ &= \left[Q^n \mid R^n \right] \left[\begin{array}{c|c} SQ^n & 0 \\ \hline 0 & SR^n \end{array} \right] \left[\begin{array}{c|c} E^{i(n)} - L^n & 0 \\ \hline 0 & E^{m(n)} - K^n \end{array} \right] \left[\begin{array}{c|c} U^n & 0 \\ \hline 0 & S^n \end{array} \right] \left[\begin{array}{c} I^n \\ \hline M^n \end{array} \right] \end{aligned} \quad (1)$$

where
n: the activity number;
C^n: the unit matrix of the cost;
$c(Y^n_{y(n)})$: the cost of the output $Y^n_{y(n)}$.

This matrix calculates the cost of the products or the semi-manufactured products $Y^n_{y(n)}$ in activity An.

Details of each matrix are as follows:

Q_n is the amount of material required to make $Y^n_{y(n)}$.

$$Q^n = \begin{bmatrix} q^n_{11} & q^n_{12} & \cdots & q^n_{1n} \\ q^n_{21} & q^n_{22} & \cdots & q^n_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ q^n_{y(n)1} & q^n_{y(n)2} & & q^n_{y(n)n} \end{bmatrix} \quad (2)$$

q^n_{ij} is the amount of material or semi-manufactured product j required to make semi-manufactured products or product i in activity An.

R^n is the operating time of material required to make $Y^n_{y(n)}$.

$$
R^n = \begin{bmatrix} r^n_{11} & r^n_{12} & \cdots & r^n_{1m(n)} \\ r^n_{21} & r^n_{22} & \cdots & r^n_{2m(n)} \\ \vdots & \vdots & \ddots & \vdots \\ r^n_{y(n)1} & r^n_{y(n)2} & \cdots & r^n_{y(n)m(n)} \end{bmatrix} \tag{3}
$$

$r^n{}_{ij}$ is the operating time of material or semi-manufactured products *j* required to make semi-manufactured products or products in activity *An*.

SQ_n is the rate of the material matrix depending on the requested size.

$$
SQ^n = \begin{bmatrix} sq^n_1 & 0 & \cdots & 0 \\ 0 & sq^n_2 & \cdots & \vdots \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & sq^n_{y(n)} \end{bmatrix} \tag{4}
$$

$sq^n{}_{ij}$ is the rate at which materials or semi-manufactured products *j* are used to make semi-manufactured products or products *i* depending on the requested magnitude of activity *An*. Final product changes are made according to customer requests, which create variations in the amount of materials, semi-manufactured products, and human resource consumption.

SR^n is the rate of operating time matrix depending on the requested size.

$$
SR^n = \begin{bmatrix} sr^n_1 & 0 & \cdots & 0 \\ 0 & sr^n_2 & \cdots & \vdots \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & sr^n_{m(n)} \end{bmatrix} \tag{5}
$$

$sr^n{}_{ij}$ is the rate of at which material or semi-manufactured products *j* required to make semi-manufactured products or products *i* depending on the requested magnitude of activity *An*. Final product changes are transformed according to customer requests, which create variations in the amount of materials, semi-manufactured products, and human resource consumptions.

L^n is the rate of the material loss.

$$
L^n = \begin{bmatrix} l^n_1 & 0 & \cdots & 0 \\ 0 & l^n_2 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & l^n_{i(n)} \end{bmatrix} \tag{6}
$$

l^n is the rate of the material loss for each output, which is calculated as the rate of the material yield from the unit matrix subtracting L^n.

K^n is the rate of the operating loss.

$$K^n = \begin{bmatrix} k_1^n & 0 & \cdots & 0 \\ 0 & k_2^n & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & k_{m(n)}^n \end{bmatrix} \quad (7)$$

$k^n{}_k$ is the rate of the operating loss for each output, which is calculated as the formal operating time from unit matrix subtracting K^n.

U^n is the material cost per unit.

$$U^n = \begin{bmatrix} u_1^n & 0 & \cdots & 0 \\ 0 & u_2^n & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & u_{i(n)}^n \end{bmatrix} \quad (8)$$

$u^n{}_k$ is the cost per unit of material or semi-manufactured products k in activity An.

S^n is the operating time per unit.

$$S^n = \begin{bmatrix} s_1^n & 0 & \cdots & 0 \\ 0 & s_2^n & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & s_{m(n)}^n \end{bmatrix} \quad (9)$$

$s^n{}_k$ is the operating time per unit of the equipment or stuff k in activity An.

I^n is the amount of the material flow.

$$I^n = \lfloor I_1^n \; I_2^n \cdots I_{i(n)}^n \rfloor \quad (10)$$

$I^n{}_k$ is the amount of material or semi-manufactured products k required to execute the activity An at one time.

M^n is the number of the equipment.

$$M^n = \lfloor M_1^n \; M_2^n \cdots M_{m(n)}^n \rfloor \quad (11)$$

$M^n{}_k$ is operating time of the equipment or stuff k required to execute the activity An at one time.

4. Application for company A

About Company A and the IDEF0

Applied manufacturing company, called "Company A," engages in processes to make wires from plastic. This wire product (Figure 2) is utilized for a paper making company, uses an impure substance during filtering, and transfers the pulp as an endless conveyor (Figure 3).

Figure 4 illustrates the IDEF0 of Company A's manufacturing process. The four important activities are as follows: A1 represents base fabric manufacturing, A2 represents the stock process for the base fabric manufacturing, A3 represents the finished product, and

A4 represents the delivery process. In detail, A1 represents the process that transforms plastic into grainy wire. The plastic is supplied by other companies, which develop a delivery time schedule plan. The grainy wire is called the "base fabric net." A3 represents the finished product ordered from a customer, and A4 represents the delivery activity to the customer, including packaging.

Figure 2: Finished product

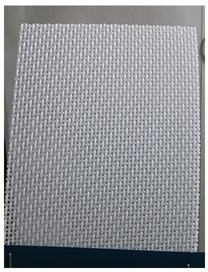


Figure 3: Situation in which the finished product is utilized

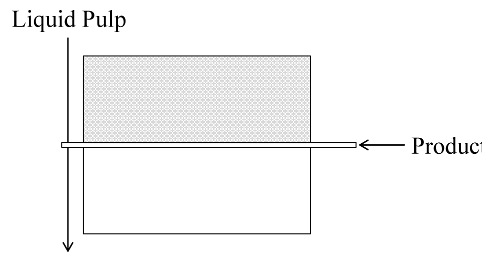


Figure 4: Typical manufacturing process

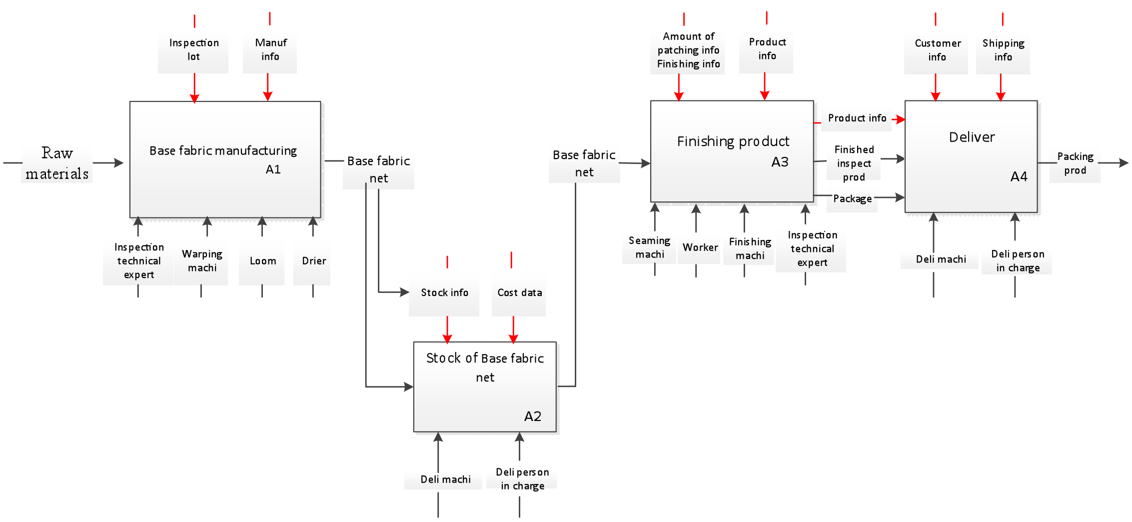


Figure 5 illustrates the nested structure of the A1 activities. At activity A11, raw materials are checked for their strength, length, density, and other specifications. Activity A12 represents warping, which is a preparation process for looming the wire using a looming machine. The raw material is prepared into a wire rolled by a tubular, such as in Figure 6. Activity A13 represents weaving the wire through the looming machine. Activity A14 represents the heat set process in which the weaving wire becomes the base fabric net through heating.

Figure 5: Nested structure of A1 activity

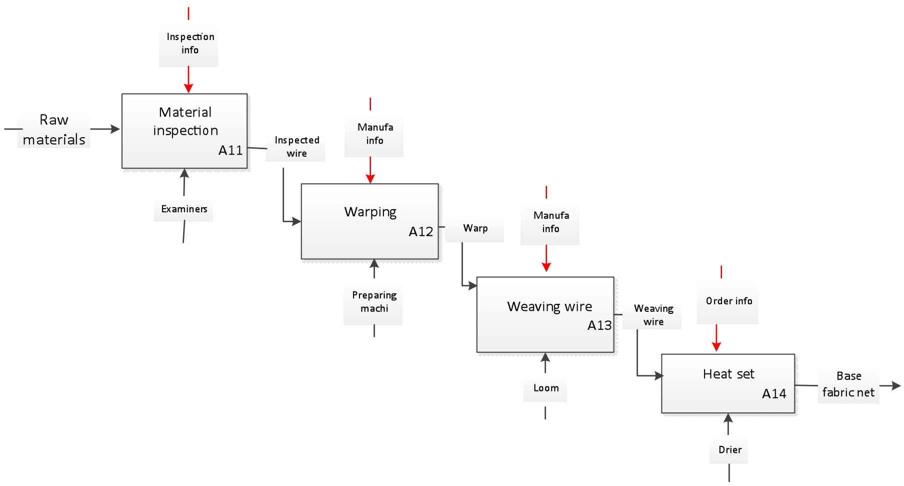


Figure 6: Warp for the loom

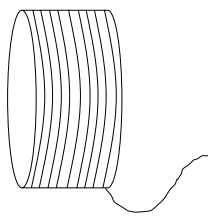


Figure 7 illustrates the nested structure for the A3 activities. The A31 activity, which represents measuring, is a cutting process according to the customer's order information. Activity A32, which involves a seaming wire, represents poaching the wire with human hands (Figure 8). Company A has a significant problem executing this activity, which takes a long time to process, generates high costs, and is based on order information for net size and volume. Ordering the product to delivering the product to the customer requires significant lead-time. Consequently, a large volume of base fabric nets is stocked at processing activity A2, "stock for base fabric net."

Figure 7: Nested structure of A3 activity

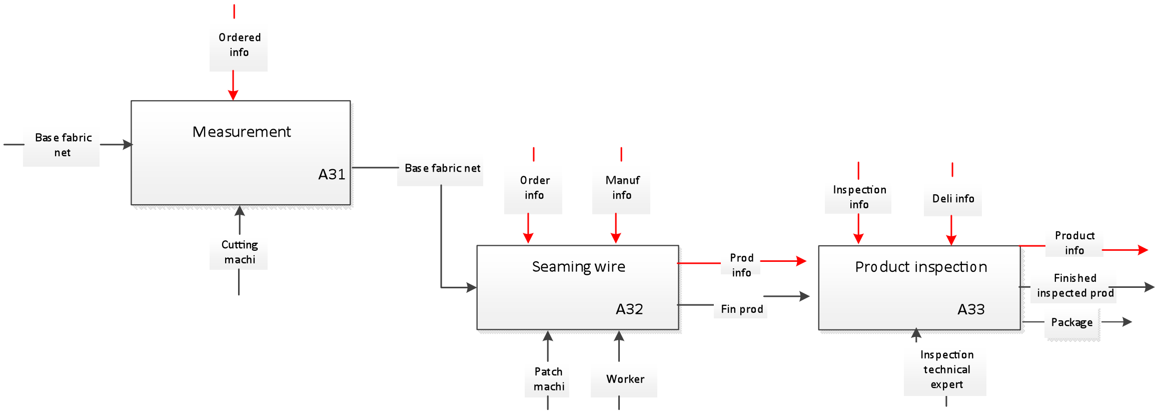
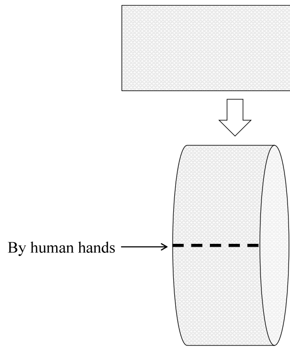
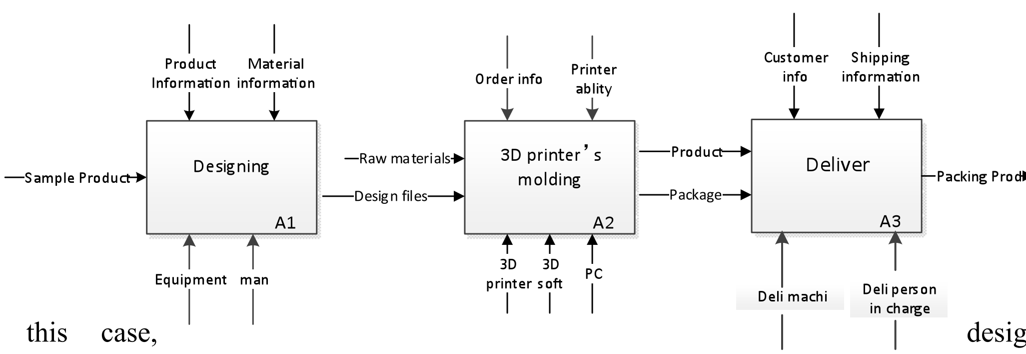


Figure 8: Activity A32



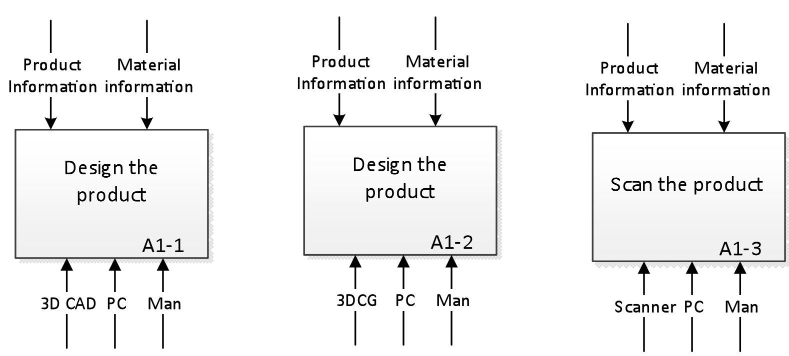
Next, 3D printing technology is applied to Company A, as shown in Figure 9. In this case, three activities occur: A1 represents design, A2 represents the 3D printer's molding, and A3 represents the delivery process.

Figure 9: 3D process



In this case, design uses three methods (Figure 10). First, the product is designed using a 3D computer-aided design (CAD). Second, a 3D computer graphic is used. Finally, a 3D scanner scans a sample product or a final molded product and converts a 3D spatial image to a digital file. The digital file flows from the output of A1 to the input of A2.

Figure 10: Alternative processes of the 3D A1 process



Using the digital file and the raw materials, activity A2 prints the finished product using the 3D printer. The printing speed depends on the 3D printer's output size, buildup speed, and graphic mode. There are different types of the 3D printer. In this study, equations (4) and (5) are applied to the output cost and time according to the printer's ability.

5. Calculate and study the cost of the typical manufacturing and 3D printing processes

In this chapter, each activity's cost is calculated using the cost-matrix method. The initial data and the parameters are used in the calculation. Table 1 provides the initial data on the rate of material loss, operating cost, and time per unit, and determines the 3D printer's ability.

Table 1: Initial data

A unit cost		The rate of yield	
Wire cost per g	500	Inspected wire	1.000
Package cost	1,000	Warping	1.000
Processing costs per mm		Weaving	0.980
Material inspection cost	20,000	Heat set	1.000
Warping cost	100,000	Base fabric	1.000
Weaving cost	100,000	Seaming	0.950
Drier	50,000	Measurement	1.000
Delivery machine	50,000	Finished product inspection	1.000
Stock hour cost	1,000	Total rate of yield	0.931
Seaming cost (machine)	200,000	3D Molding time	
Seaming cost (human)	1,000		
Measurement cost	20,000	Variable	Partial regression coefficient
Finished product inspection cost	20,000	Parameter α	0.194
		Parameter β	0.755
		Parameter γ	0.202
		Constant term A	-3.930

Equipment processing costs, such as warping costs, are calculated as depreciation divided by the equipment's operating time throughout the year. Equipment time influences the equipment's ability per hour. Human processing cost is a fixed hourly wage for each activity. Setting the molding time is difficult because of the various types of 3D printers. Each printer's ability is different with respect to molding time, resolution, lamination pitch, and other characteristics. This study assumes that the 3D printer's ability is decided on by the input data, including width, depth, and height. As a result, the following formula calculates the molding time.

$$\begin{pmatrix} t_1 \\ t_2 \\ \vdots \\ t_n \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ A_{m1} & \cdots & \cdots & A_{mn} \end{pmatrix} \times \begin{pmatrix} w_1^{\alpha_1} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & w_n^{\beta_n} \end{pmatrix} \times \begin{pmatrix} d_1^{\beta_1} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & w_n^{\beta_n} \end{pmatrix} \times \begin{pmatrix} h_1^{\gamma_1} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & w_n^{\gamma_n} \end{pmatrix} \quad (14)$$

A_{mn}, α_n, β_n, and γ_n are the parameters assumed in a multivariate analysis. Measured value refers to real 3D printing time for a ProJet 5500. Therefore, printing time (t_n) must be forecasted from real printing data. In this manner, the operating and 3D printing time and cost assist in calculations using the cost-matrix method.

Table 2 lists each processing time taken to develop the final product assuming a width of 100 mm, depth of 200 mm, and height of 50 mm. Using the lists, total processing time of both the typical manufacturing process and the 3D process can be estimated.

Table 2: Processing time

Usual process	
Inspection	5.000
Warping cost	10.000
Weaving cost	3.000
Hear set	2.000
Delivery machine	1.000
Seaming machine	10.000
Seaming machine	7.500
Measurement	2.000
Fin-prod inspection cost	3.000
Stock	50.000
3D process	
3D molding time	5.768
3D design time	3.846

Table 3 presents a calculation process for the unit cost in A1's nested activity. The left column represents "Activity." "ICOM" and "Content" are from the IDEF0. "Total price" represents the material cost of the input and output of the "Contents." The calculation of the total price is the sum of "Quantity after loss" multiplied by "Unit price per quantities." The total cost of the processing price is calculated using the mechanism in Table 3. The total cost of the processing time is calculated multiplying the processing time from Table 2 by the "Unit price per processing." For example, A12's warping process used 500 g of wire input, which changed to a net 2,000 mm^2 through the activity. From this output, the material cost was 500 g of wire multiplied by 500 yen from Table 1, or 250,000 yen. To calculate the unit cost, the 250,000 yen was divided by 2,000 mm^2 of net warping, for 125 yen, which goes to A13's input unit cost per quantity. To determine net warping, a warping machine needs to operate for five hours. The machine cost was 500,000 yen and the cost to prepare the wire for the machine was 1,000 yen. Finally, the total processing cost was 1,000,000 yen for activity A12, and 500 yen was the unit cost for each occurrence of the activity.

Table 3: Activity A1's calculation process of unit cost

Activity		ICOM	Content	Quantity	Quantity after the loss	Unit price per quantities	Total price	Processing time	Unit price per processing	Processing price
A1:Base fabric manufacturing	A11:Material inspection	Output	Inspected wire	100 g	100 g					
		Mechanism	Examiners					5 h	20,000 ¥/h	100,000 ¥
		Control	Inspection info	100 g						
		Input	Raw material	100 g		500 ¥/g	50,000 ¥			
		Total					50,000 ¥			100,000 ¥
		Unit cost with loss					500.00 ¥			1,000.00 ¥
	A12:Warping	Output	Warping net	2,000 mm2	2,000 mm2					
		Mechanism	Warping machine					5 h	100,000 ¥/h	500,000 ¥
		Control	Manufacturing info							
		Input	Inspected wire	500 g	500 g	500 ¥/g	250,000 ¥		1,000 ¥/h	500,000 ¥
		Total					250,000 ¥			1,000,000 ¥
		Unit cost with loss					125 ¥			500.00 ¥
	A13:Weaving wire	Output	Weaving wires	1,500 mm2	1,470 mm2					
		Mechanism	Loom					3 h	100,000 ¥/h	300,000 ¥
		Control	Manufacturing info							
		Input	Warping net	1,500 mm2	1,500 mm2	125 ¥/mm2	187,500 ¥		500 ¥/h	750,000 ¥
		Total					187,500 ¥			1,050,000 ¥
		Unit cost with loss					127.55 ¥			714.29 ¥
	A14:Heat set	Output	Base fabric net	500 mm2	500 mm2					
		Mechanism	Drier					2 h	50,000 ¥/h	100,000 ¥
		Control	Manufacturing info							
		Input	Weaving wires	500 mm2	500 mm2	127.55 ¥/mm2	63,776 ¥		714.29 ¥/h	357,145 ¥
		Total					63,776 ¥			457,145 ¥
		Unit cost with loss					127.55 ¥			914.29 ¥

Table 4 indicates the 3D manufacturing calculation process through a selection of the case of "A1-3." In the A1-3 activity, the mechanism needs 3.85 hours of activity to scan the product.

Table 4: 3D manufacturing calculation process in case of the "A1-3."

Activity		ICOM	Content	Quantity	Quantity after the loss	Unit price per quantities	Total price	Processing time	Unit price per processing	Processing price
A1:Making the design	A1-3:Scan the product	Output	Design files	1 byte	1					
		Mechanism	Scanner					3.85 h	34.72 ¥/h	133.53 ¥
			PC					3.85 h	8.68 ¥/h	33.38 ¥
			Man					3.85 h	1000 ¥/h	3845.56 ¥
		Control	Product Information							
			Material Information							
		Input	Sample Product	1 m	1					
		Total								3979.09 ¥
		Unit cost with loss								3979.09 ¥
A2:3D printer's molding		Output	Product	100 mm	100 mm	500 \/g	50,000 ¥			
			Package							
		Mechanism	3D printer					5.77 h	347.22 ¥/h	2002.90 ¥
			3D soft							
			PC							
		Control	Order information							
			Printer ability							
		Input	Raw material	500 g		10,000 ¥/g	5,000,000 ¥		3979.09 ¥/h	1989544.57 ¥
			Design files							¥
		Total					5,000,000 ¥			1991547.46 ¥
		Unit cost with loss					10,000 ¥			19915.47 ¥
A3:Delivery		Output	Packing product	100 mm	100 mm					
		Mechanism	Delivery machine					10 h	260.42 ¥/h	2604.17 ¥
			Delivery person in charge					1 h	1000 ¥/h	1000.00 ¥
		Control	Customer information							
			Shipping information							
		Input	Finished inspected product	100 mm		1,000.00 ¥/mm	100,000 ¥			
			Product information							
			Package	1 m		100.00 ¥/mm	100 ¥			
		Total					100,100 ¥			3604.17 ¥
		Unit cost with loss					1,001 ¥			36.04 ¥

Table 5: Total material processing cost

Cost item	Material cost	Processing costs	Total
Material cost			
Wire	134.26		134.26
Package	10.00		
Processing costs			
Inspection cost		268.53	268.53
Warping cost		268.53	268.53
Weaving cost		214.82	214.82
Loom cost		210.53	210.53
Delivery equipment cost		105.26	105.26
Delivery person in charge		105.26	105.26
Seaming cost (human)		6.58	6.58
Measurement cost		80.00	80.00
Finished prod inspection cost		600.00	600.00
Subtotal	144.26	1,859.51	2,003.77
Total	144.26	1,859.51	2,003.77

Cost item	Material cost	Processing costs	Total
Material cost			
Resin	500		500
Package	100		100
Processing costs			
Design soft cost		133.53	133.53
Design equipment cost		33.38	33.38
Designer's cost		3845.56	3845.56
Molding cost		20.03	20.03
Delivery equipment cost		26.04	26.04
Delivery human cost		10	10
Subtotal	600	4068.54	4668.54
Total	600	4068.54	4,668.54

Table 5 indicates the total material cost and processing cost for width 100 mm, depth 200 mm, and height 50 mm. The material cost is calculated using the cost-matrix method, which produces a material cost subtotal of 144.26 yen in the typical process. The processing cost subtotal is 1,859.51 yen, resulting in a total manufacturing process cost of 2,003.77 yen for the typical process. For the 3D process, the total cost is 4,668.54. Therefore, the typical manufacturing process has a lower cost than the 3D technology process, indicating that the standard decision made favors this typical manufacturing process for wire of width 100 mm, depth 200 mm, and height 50 mm. In the detailed cost analysis, the seaming cost incurred by humans is 6,358 yen. The seaming wire process of the typical manufacturing process is time consuming if the required final product volume is produced; consequently, it requires more labor and equipment processing hours. This activity also incurs significant production costs, which change depending on the size of the final product.

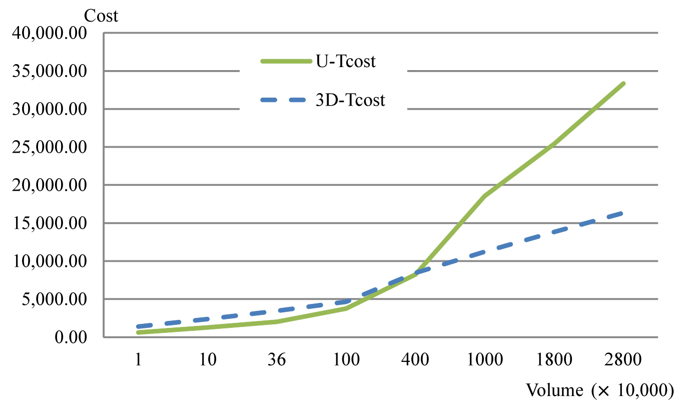
Therefore, sensitivity analysis is conducted on the size of the final product. Table 6 represents the alternative plan and the outputs for the cost. Figure 11 depicts a transition in volume and the total activity cost. The volume is calculated from multiplying width, depth, and height. This output shows that the typical manufacturing process is less expensive than the 3D method for small order volumes. However, after volumes of 4,000,000, the typical manufacturing process becomes more expensive than the 3D method because of the related human costs. Therefore, higher volumes require longer final processing time to complete the product. In contrast, the 3D process' cost increases are as gradual as the volume increases.

This comparison indicates that this study can determine a changing optimal point from the typical process to the 3D process.

Table 6: Outputs of the sensitive analysis

W	D	H	Volume	U-Tcost	3D-Tcost
20	50	10	10,000	624.79	1,384.92
50	100	20	100,000	1,276.71	2,372.33
60	150	40	360,000	2,019.93	3,445.67
100	200	50	1,000,000	3,758.16	4,668.54
100	400	100	4,000,000	8,235.63	8,462.31
200	500	100	10,000,000	18,540.46	11,231.99
200	600	150	18,000,000	25,399.96	13,831.86
200	700	200	28,000,000	33,333.55	16,346.12

Figure 11: Transition of the sensitive analysis



6. Managerial Implication

For discussion of a managerial implication, the member of the company A are provided possibilities and future tasks if the 3D printing technology introduced to the practical company. Possibilities of the application are as follows:

• The base fabric is produced by make-to-stock manufacturing, and the product with the peculiar order size is assigned to it in measurement process. The 3D printing technology is able to produce the product without assignment of the base fabric. Therefore, they expect to significantly increase the rate of the yield.

• It is able to cut the human cost because of the omitting many processes. The process of the seaming wire, especially, has the highest human cost. Therefore, they expect to significantly decrease the rate of manufacturing cost in accordance with the omitting of that process.

• They have the production lead-time between 1.5 and 3.0 months. According to the printing ability, the omitting many processes by the 3D printing technology affect our production lead-time. Therefore, they expect to significantly reduce the production lead-time.

On the other hand, they give future tasks such as:

• A product realization needs to discuss such as a size of the products, the diameter of each monofilament such as the raw materials for actual products, the mesh count as the number of monofilament per inch, and so on.

• A correspondence of the resin specifications as the raw materials must check as PET, PEEK, the resin including carbon, and so on.

• Evaluation of the physical properties is necessity from viewpoints of inspection of the products: ultimate tensile strength, stretch rate, aeration, and so on. The aeration is a passage degree of air through the mesh.

7. Conclusion

To grasp the cost structure is an aspect of the competitiveness of a company's strength. Studying the method for discussing costs is inadequate. Changing the concept of the process activity and the cost understanding to introduce 3D printing is also possible. In this study, the typical manufacturing process and the introduction of 3D printing technology are analyzed in a real wire frame company. Due to this, the IDEF0 method was introduced to understand the processing activities, and the cost-matrix method was adopted to determine the cost structure. This study clarified the following future issues related to the introduction of 3D printing technology:

• Design information is very important for introducing 3D printing technology. In short, design information influences the processing time and finished quality. If complicated design is prepared, printing time may increase and quality satisfaction may be reduced. In this simulation of the 3D design process, the scanner technology was selected to understand and calculate the cost and the activities. In a real situation, revising and modifying the design after scanning the product is important. As a result, in future, we aim to consider the cost of the design information.

• Introducing 3D printing technology in the wire frame company enabled a discussion of the cost considerations. However, considering the profits or the distribution of value-added is also required.

• Even the 3D printer process requires material stock. Therefore, the stock point and cost must be considered, as well as the cost related to logistics, time, and activity.

• The ability to engage in 3D printing is a virtual assumption in this study. In a real situation, the stacking pitch decides the printing performance because this pitch determines the printing time. Currently, depending on the 3D printer, printing a 10 cm-tall figure takes one hour. The hope is that future 3D printers will have improved performance and produce higher quality at lower costs.

As a result, this study provided the following outcomes: 1) an understanding of the cost structure for each activity in the real company, 2) a discussion of a typical manufacturing process and the introduction of the 3D printing process through a sensitive analysis, and 3) clarifying future discussions regarding the introduction of 3D printing technology.

Numerous areas exist for future research, including applications to other companies and using real numerical examples.

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References

Anderson, C. (2012), “MAKERS: The New Industrial Revolution”, *Random House Business Books.*

Bargelis, A. & Stasišk, A. (2008), “IDEF0 modelling technique to estimate and increase the process capability at the early product design stage”, MECHANIKA, 3 (71): 1392-1207.

Campbell, T., Williams, C., Ivanova, O. & Garrett, B. (2011), “Could 3D Printing Change the World? Technologies, Potential and Implications of Additive Manufacturing”, A Strategic Foresight Report from the Atlantic Council.

Foroozmehr E, Lin D & Kovacevic R (2009), “Application of Vibration in the Laser Powder Deposition Process”, *Journal of Manufacturing Processes*, 11 (1): 38-44.

G.Q., J., W.D, L. & Gao, L. (2013), “An Adaptive Process Planning Approach of Rapid Prototyping and Manufacturing”, *Robotics and Computer-Integrated Manufacturing*, 29 (1): 23-38.

Ishii, T., Kumagai, S. & Ohba, M. (2012), “Real-time Supply-demand Balance Model in the Cloud Computer Age - Activity Based Cost Modeling Method for Grasping Cost Variations Caused by the Market Environment Change”, *Japan Industrial Management Association, Proceeding in Spring:* 32-33.

Karunakaran, K.P., Suryakumar, S., Pushpa, V. & Akula, S. (2010), “Low Cost Integration of Additive and Subtractive Processes for Hybrid Layered Manufacturing”, Robotics and Computer-Integrated Manufacturing, 26 (5): 490-499.

Kenney, M. (2013), “Cost Reduction through the Use of Additive Manufacturing (3D Printing) and Collaborative Product Life Cycle Management Technologies to Enhance the Navy's Maintenance Programs”, Monterey, California: Naval Postgraduate School.

Kumagai, S. (1998), “IDEF0 Model and the Making Process”, *Journal of the Japan Society for Management Information,* 6 (4): 97-100.

Leukers, B., Gülkan, H., Irsen, SH., Milz, S., Tille, C., Schieker, M. & Seitz, H. (2005), “Hydroxyapatite Scaffolds for Bone Tissue Engineering made by 3D Printing”, *Journal of Materials Science: Materials in Medicine*, 16 (12): 1121-1124.

Lim, S., Buswell, R.A., Le, T.T., Austin, S.A., Gibb, A.G.F. & Thorpe, T. (2012), “Developments in Construction-scale Additive Manufacturing Processes”,*Automation in Construction*, 21: 262-268.

Nakamura, Y., Ohba, M., Kumagai, S., Hayashi, C. & Oomiya, N. (2014), “Application of the Activity Cost Model to 3D Printer Technology”, The Proceedings of 19th International Symposium on Logistics (ISL 2014): 482-489.

Parthasarathy, J., Starly, B. & Raman, S. (2011), “A Design for the Additive Manufacture of Functionally Graded Porous Structures with Tailored Mechanical Properties for Biomedical Applications”, Journal of Manufacturing Processes, 13 (2): 160-170.

Qian, L. & Ben-Arieh, D. (2008), “Parametric Cost Estimation Based on Activity-Based Costing: A Case Study for Design and Development of Rotational Parts”, *International Journal of Production Economics*, 113 (2): 805-818.

Silva, DN., Oliveira, M., Meurer, E., Meurer, MI., Silva, JV. & Santa-Bárbara, A. (2008), "Dimensional Error in Selective Laser Sintering and 3D-printing of Models for Craniomaxillary Anatomy Reconstruction", Jo*urnal of Cranio-Maxillofacial Surgery,* 36 (8): 443-449.

Sisson, A. & Thompson, S. (2012), "Three Dimensional Policy: Why Britain needs a Policy Framework for 3D Printing", Study of Big Innovation Centre, London, Washington.

Zhang, J. & Khoshnevis, B. (2013), "Optimal Machine Operation Planning for Construction by Contour Crafting", *Automation in Construction,* 29: 50-67.

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