A methodology for the selection of manufacturing processes based on the design of the Manufacturing Matrix

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Abstract

This study proposes a decision method to help designers and engineers select the manufacturing process that meet the production performances, including environmental impacts. It has intended to make a decision on manufacturing parameters such as quality, time, cost and environmental impact. The methodology is structured and supported by a matrix called the manufacturing matrix. It is used to evaluate the relationships between the manufacturing process of each product attribute and the process parameters. The method is in 4 steps: create the manufacturing matrix, generate the solutions, evaluate the solutions and select the manufacturing process. The methodology is applied on an industrial case study in the leather good industry. It is able to help practically designers and engineers select the suitable manufacturing process.

***Keywords**: product design, manufacturing process, design for manufacturing, leather goods*

1 Introduction

During the development of a new product, or the redesign of an existing one, the product development team is confronted with a variety of design criteria like quality, ergonomics, safety, environment, aesthetics, etc. Owing to environmental problems such as global warming, climate change, pollution, health, working circumstances and safety, environmental impacts are a new aspect which most customers have just started to consider before purchasing the new product. It is a new criterion which is essential to develop products for the 21st century. The products that will not meet these concerns will be rejected by customers. Products that increase the environmental burden have no future. This point of view originated in Europe [1], and is being to expand worldwide soon. Then, companies are challenged with new questions of what environmental issues are the most relevant for their business and how to consider them in relation to the products that they are developing. In particular, it is quite relevant to understand how design changes can affect the environmental performance of the new product concepts early in the design process.

Leather goods are one of the fashion products. They are the most carried accessories in everyday life. The leather goods industry in Thailand is facing a severe competition in the global market. It is due to the quality of products that do not meet customer's requirements. Especially, the European market is interested in products that do not make any effect on the environment. By the way, manufacturers in Thailand are still producing products by traditional manufacturing processes that are not friendly with the environment. Thus, the European market does not accept products from Thailand.

From this important challenge for Thai leather goods manufactures, we could say that current manufacturing practices are both ineffective and inefficient, and consequently fail to deliver an optimal result in environmental aspects. Then, Thai manufacturers need to adapt the design and manufacturing strategy to respond to continuous change of customers by integrating the environmental impacts assessment in the design process, alongside with the classical manufacturing performances as quality, time and cost.

The purpose of this study was to propose the methodology to help designers and engineers select the manufacturing process that ensured to make friendly with environment in addition to cost, time and quality performances. This paper is organized as follows: Section 2 presents the literature review. Section 3 is the research methodology. The determination of the process parameters is illustrated in section 4. We propose the methodology in section 5 and apply it on a case study in section 6. The conclusion is drawn in section 7.

2 Literature review

2.1 *The life cycle of products*

A life cycle approach is to assess the environmental impacts in conjunction with economic impacts under consideration of technical boundary conditions. The product life cycle starts with the extraction, processing and supply of the raw materials and energy needed for the product. It then covers the production of the product, its distribution, use (and possibly reuse and recycling), and its ultimate disposal as shown in Figure 1. Environmental impacts of all kinds occur in different phases of the product life cycle and should be accounted for in an integrated way. Key factors are the consumption of input materials (water, non-renewable resources, energy in each of the life cycle stages) and production of output materials (waste, water, heat, emissions, and waste) and factors like noise, vibration, radiation, and electromagnetic fields. The environmental challenge is to design products that minimize environmental impacts during the entire product life cycle.

2.2 *Design for manufacturing*

Traditionally, design was done for functionality and less effort was used to evaluate how well the design would be manufactured. Therefore, methods to promote design for manufacturing (DFM) have evolved since the 1970s [2]. Design for manufacture or 'Manufacturability' concerns the cost and difficulty of making the product [3]. The process of proactively designing products to: a) optimize all the manufacturing functions: fabrication, assembly, test, procurement, shipping, delivery, service, and repair and b) assure the best cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction [4]. Many studies developed the DFM methodology to develop new product, achieve quality, customize product and reduce cost [5] [6]. Thus, any modern design methodology must lean on DFM methodology [7] and consequently our methodology must help designers evaluate the manufacturing processes in the design process.

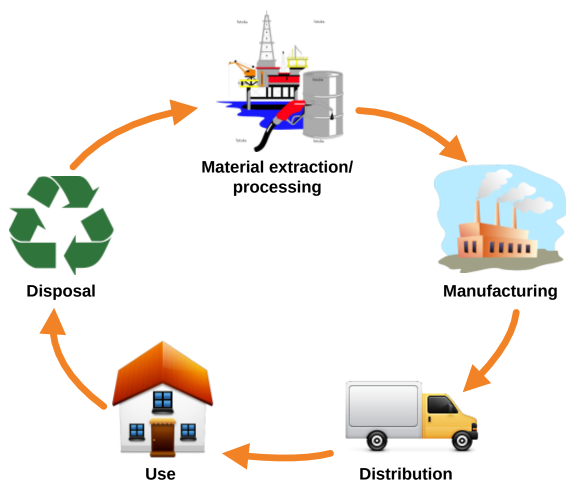

Figure 1: The life cycle of products

2.3 *Design for environment*

Design for Environment (DFE) originated in the early 1990s due to the convergence of several driving forces that made global manufacturers more aware of the environmental implications of their product and process designs [8]. DFE is the systematic consideration of design performance with respect to environmental, health, safety, and sustainability objectives over the full product and process life cycle [9] [10]. The aim is to design products that are functional, attractive, cost effective, and have no harmful side effects for human health or the environment. DFE is often referred to by other names, including Eco-Design, Life-Cycle Design and Sustainable design [8]. Most of the recent design studies focused on design for environment such as food packaging [11], leather [12] [13] [14], leather goods [15], textile [16] [17] and footwear [18]. Thus, designing products with reduced environmental impacts during the entire product life cycle is mainly our challenge [19].

2.4 *Quality Function Deployment*

Quality function deployment (QFD) is an important product development method. It is most commonly used in the early design phase of the design process [20]. QFD originated in the late 1960s and early 1970s in Japan from the work of Akao [21]. QFD is a systematic method for translating the voice of customers into a final product through various product planning, engineering and manufacturing stages in order to achieve higher customer satisfaction [22]. QFD is typically viewed as a four-stage process to design products that optimally meet customer needs. The first phase is to collect customer needs for the product (or customer requirements, customer attributes) called WHATs and then to transform these needs into technical measures (or technical requirements, product design specifications, engineering characteristics, performance measures, substitute quality characteristics) called HOWs. The second phase transforms the prioritized technical measures in the first phase into part characteristics, called Part Deployment. Key part characteristics are transformed in the third phase, called Process Planning, into process parameters or operations that are finally transformed in the fourth phase called Production Planning into production requirements or operations [23]. Thus, QFD is applied in this study to create the structure of the matrix and evaluate the relationships between the manufacturing process of each product attribute and the process parameters.

3 Research methodology

The research methodology was composed of six steps as shown in Figure 2.

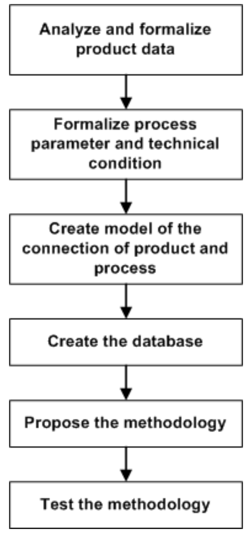

Figure 2: The steps of the research methodology

Analyze and formalize product data: We analyzed and formalized the product data from both the experience of expert designers and literature [24]. We focused on the leather bag that is composed of four types of elements: shape, handle, accessories and details as shown in Figure 3.

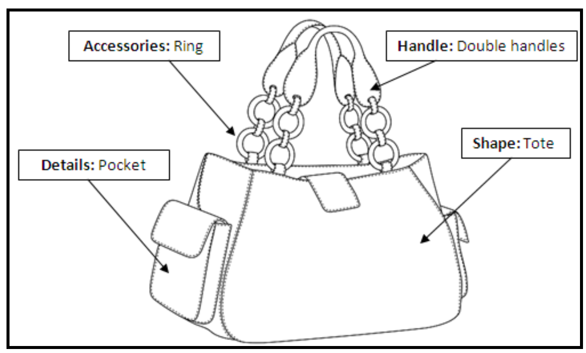

Figure 3: The elements of the bag

Formalize process parameters and technical conditions: The detail of formalizing the process parameters is explained in section 4.

Create the model of the connection of product elements and process parameters: The product structure gives the product elements. Each product elements can be made from different manufacturing processes. The product-process model was classified in four levels as shown in Figure 4. The first level is product. The second level is product elements. The third is the manufacturing techniques of each product element. The forth level is the process sequence of each manufacturing technique.

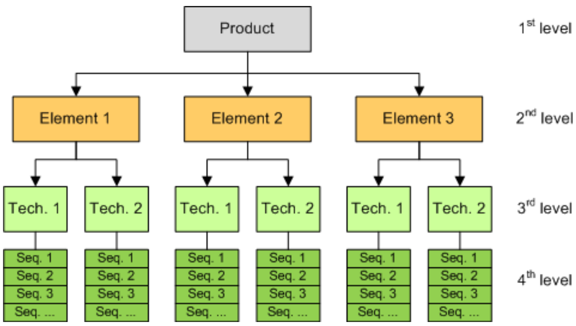

Figure 4: The model of the connection of product and process

Create the database: The product-process model was implemented in a database which structure is based on three elements: product data, material data and manufacturing process data. See section 4 for the content of the database.

Propose the methodology: Based on our experience in the company (we staid 6 months working in the company and developing products adapted to the manufacturing processes) and the methodology from literature, a design methodology was summarized. The detail of methodology is explained in section 5.

Test the methodology: The methodology was finally tested on a complete industrial case study. Section 6 illustrates the methodology on an industrial case study.

4 The manufacturing database

4.1 *The general manufacturing database*

The database of manufacturing matters is very classical at the top level. It refers to material and process candidates.

- Material that is used to make a leather bag can be classified in three groups: outside material, inside material and support material. Types and cost of each material are stored in the database.
- The manufacturing process of leather bags can be classified in nine steps: pattern cutting, cutting, splitting, skiving, assembling, coloring, stitching (sewing), fastening accessories and finishing.

  The sequence of operations (process) and the manufacturing time of each product element are stored in the manufacturing database.

4.2 *The process parameters*

The process parameters are quality, cost, time and environmental impact.

- *Quality:* It focuses on basic functions. They are related to customer's feeling such as soft, strong and straight [25]. "Soft", a soft feeling of leather gains value from tactile dimension. "Strong", a strong structure and proportional dimensions gains value from visual and tactile dimension. "Straight", smooth outside of the bag likes a straight line that gains from visual dimension. Quality characteristics are directly associated with the manufacturing processes and the materials.
- *Time:* It focuses on the manufacturing time of each product element.
- *Cost:* It focuses on the direct labor and material costs.
- *Environmental impact:* Life cycle assessment technique (LCA) is used to identify and assess the environmental impacts of leather goods industry. Finally, four environmental criteria were retained as relevant for the product life cycle as shown in Figure 5. Based on the literature, the relevance was ranked from +++ as maximum dependence to 0 where the dependence was considered to be under the threshold of relevance.

Environmental Criteria	Raw material	Manufacturing	Use	EOL
Water consumption	+++	0	0	0
Energy consumption	+	++	0	0
Toxic emission	+	+++	0	0
Recyclability	0	0	0	++

Figure 5: The impact matrix (relevance of environmental criteria against lifecycle phases)

Leather and cotton are usually raw material for making leather bags. Water consumption is very significant impact of the manufacturing processes of leather and cotton because they are chemical intensive industry [26] [27]. The other impacts were considered to be less critical in the raw material stage. Thus, water consumption was selected.

The manufacturing and assembly stage is characterized by using lots of machines alongside with manual techniques. Energy consumption was selected as the most critical impact of this phase. Most of the electricity produced in Thailand is not based on renewable and clean technology, but on thermal power plants because they have high efficiency and capacity and long service life [28]. This industry is also considered for its toxic emissions produced from gluing and painting processes. The adhesive is used to assemble components through stitching (sewing) and the most frequently used are solvent based. Lacquer and thinner, which are solvent based, are mostly used in painting processes. Solvent based conveys to risks such as environment impact and harmful effects for the human being. Then, toxic emission was also selected for the manufacturing stage.

Use stage was decided not to have environmental impacts because the leather bags do not need energy when used.

We can address End-of-Life (EOL) of leather goods by recondition, reuse, recycling and energy recovery. Recycling of post-consumer finished leather is not currently available [29]. Only accessories of leather goods can be reused and recycled due to their production from metal or plastic. Thus, EOL stage focuses on recyclability of accessories. It can be defined in 2 directions: reuse and recycling. Reuse depends on the difficulty of disassembly. Recycling focuses on the process to separate materials. It depends on the difficulty to separate, the existence of the recycling process and the difficulty to recover.

Standard values for water consumption, energy consumption and toxic emissions were defined and stored in the manufacturing database (see section 5 for examples).

5 The proposed methodology

The methodology for selecting the manufacturing process is shown in Figure 6. It is intended to help the designers and engineers select the manufacturing process that fits quality, time, cost and environmental impacts, meaning the best manufacturing performances. It is in four steps: create the manufacturing matrix, generate solutions, evaluate solutions and select the manufacturing process. The input data come from the concept of the new product that is then defined by its product elements. The output is the manufacturing process.

5.1 *Step 1: create the manufacturing matrix*

To help the designer decide to select a suitable manufacturing process that ensures to make both profit and friendly with the environment. The product attributes and the process parameters are mapped together on a matrix called the manufacturing matrix. The structure of the manufacturing matrix consists of three distinct parts: product attributes (vertically), process parameters (horizontally) and the relationships between product attributes and process parameters (the matrix cases) (Figure 7).

The product attributes are both the individual parts composing the product and the assembly steps composing the assembly process. Different techniques can be candidate for every product element. For example, techniques HT1 (folding technique) and HT2 (painting technique) can be called for realizing the part HT (the handle tab). For each technique, a process route has been defined and validated. Finally, we can say that a line of the matrix deals with a possible process step of a technique that is candidate to perform a product attribute. The lines can be filled in independently and their relationships are kept within the matrix structure where HT is HT1 OR HT2 and HT1 consists in Cut leather AND Splitting AND Skiving AND gluing AND folding edge AND assembly with ring AND Stitching.

The head columns for the process parameter are driven by the four criteria that make the manufacturing performance: quality, time, cost and environmental impacts. Each of them is characterized by the indicators defined in the previous section, which leads to 13 indicators to estimate and calculate. Two extra columns were added to help engineers calculate more easily the interactions and their values: machine usage and raw material area.

Each case of the central matrix represents the value associated with the relationship between the process step of the product attribute and the process parameter. This estimation or calculation use various methods and techniques: direct extraction from the manufacturing database, extraction of data then reformulation, analysis by expertise.

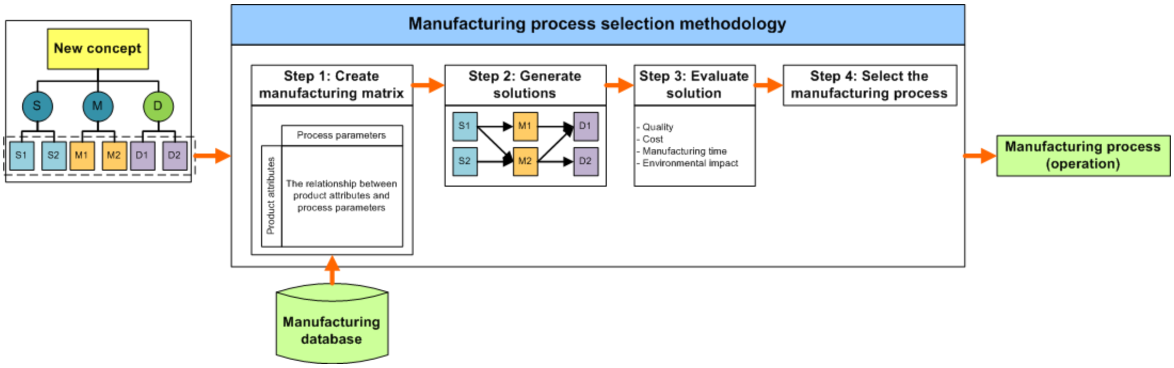

Figure 6: The methodology for the selection of the manufacturing process

			Process parameters															
			Process route	Machine usage	Raw material area (cm2)	Quality: Soft	Quality: Strong	Quality: Straight	Time (min)	Cost (Baht): Material	Cost (Baht): Labor	Environmental Impacts – Raw Mat.: Water consumption (litre)	Environmental Impacts – Manufacturing: Energy Consumption (kWh)	Environmental Impacts – Manufacturing: Toxic emission (g)	Environmental Impacts – EOL: Dissassembly	EOL: Separate	EOL: Existing recycling process	EOL: Recover
Product attribute	Handle tab (HT)	HT1	Cut leather	yes	120	3	4	5	0.5	180	2.5	1.116	0.00625		2	3	1	2
			Splitting	yes					1		5		0.05					
			Skiving	yes					1		5		0.0125					
			gluing	no					1		5			13.33				
			Folding Edge	no					5		25							
			Assembly with ring	no					1	30	5							
			Stitching	yes					3		15		0.0375					
		HT2	Cut leather	yes	88	4	4	5	0.5	132	2.5	0.8184	0.00625		2	2	1	2
			Splitting	yes					1		5		0.05					
			gluing	no					1		5			13.33				
			Assembly with ring	no					1	30	5							
			Stitching	yes					3		15		0.0375					
			Painting	no					3		15			84.52				

Figure 7: The structure of the manufacturing matrix

5.1.1 *Estimation of the elementary features*

We defined the methods and techniques to evaluate the parameters.

First of all, the process routes, the machine usages and the standard manufacturing times were retrieved directly from the manufacturing database. Quality and end-of-life parameters were evaluated by designers and engineers based on their expertise. Cost parameters (material and labour) and the other environmental impact parameters (water consumption, energy consumption and toxic emission) were calculated by designers and engineers from product and process data.

Raw material area: Quantity of material used in each the process step. The unit of measure is square centimeters (cm^2).

Quality: The Likert scale is used to evaluate the quality indicators. It is a psychometric scale commonly used in questionnaires, and is the most widely used scale in survey research. It is a bipolar scaling method, measuring either positive or negative response to a statement [30]. Data are evaluated by experts. The value scale has five levels. It is done for each of the 3 quality criteria.

1 – strongly disagree
2 – disagree
3 – neither agree nor disagree
4 – agree
5 – strongly agree

Time: The standard time of each process step is used to calculate the manufacturing time. The unit of measure is minute.

Cost: The standard costs of each process step are used to calculate the direct labor cost. This study assigns the average direct labor cost per minute. The material area that is used in each process is used to calculate the material cost. It can be calculated as follows (Equation 1).

$$C_{mat} = M_{area} \times C_{unit} \quad (1)$$

Where

C_{mat} = material cost (Baht)

M_{area} = material area (cm^2)

C_{unit} = material cost per unit (Baht/ cm^2)

Environmental impact:

- The water consumption focuses on amount of water (liter) per material (1 kg) in the manufacturing process as follows (Equation 2).

$$W_{cons} = M_{area} \times W_{mat} \quad (2)$$

Where

W_{cons} = water consumption (liter)

M_{area} = material area (cm^2)

W_{mat} = water consumption of each material (liter/cm^2) [26]

- The energy consumption depends on the machining time of each process as follows (Equation 3).

$$E_{cons} = T_{mac} \times P \quad (3)$$

Where

E_{cons} = electricity consumption (kWh)

T_{mac} = machining time (hour)

P = electric power of the machine (kW)

- The toxic emission focuses on the Volatile Organic Compounds (VOCs). VOCs are organic chemical compounds that may also be harmful or toxic. In this type of industry, VOCs emissions depend on gluing time and painting time as follows (Equation 4). The VOCs values come from the Material Safety Data Sheet (MSDS).

$$Toxic = W_{VOC} \times T_{mfg} \times U_{hour} \quad (4)$$

Where

$Toxic$ = VOCs emission (g)

W_{VOC} = weight of VOCs (g/liter)

T_{mfg} = manufacturing time (hour)

U_{hour} = hourly usage (liter/hour)

- The recyclability focuses on the reuse and recycling of accessories. Four sub-criteria are relevant: the difficulties of disassembly, separation, recovery and recycling. Data are evaluated by experts. The Likert scale is used to evaluate the difficulty of disassembly, separation and recovery. The scale value has five levels.

1 – strongly difficult
2 – difficult
3 – neither difficult nor easy
4 – easy
5 – strongly easy

The recycling difficulty is 1 when recycling processes do exist and 0 when not.

5.1.2 Generation of the manufacturing matrix

Then, the manufacturing matrix is generated for the product under consideration, still including the alternatives of product elements and assembly sets when relevant. The value of the process parameters are calculated from the elementary ones. It can be summarized as follows.

Time: The total manufacturing time is calculated as follows (Equation 5).

$$T_{total} = \sum_{i=1}^{n} T_{(i)} \quad (5)$$

Where

T_{total} = the total manufacturing time

$T_{(i)}$ = the manufacturing time of the product element

n = number of product elements

Cost: The total material cost is calculated as follows (Equation 6).

$$C_{mat(total)} = \sum_{i=1}^{n} C_{mat(i)} \quad (6)$$

Where

$C_{mat(total)}$ = the total material cost

$C_{mat(i)}$ = the material cost of the product element

- The total labor cost is calculated as follows (Equation 7)

$$C_{lab(total)} = \sum_{i=1}^{n} C_{lab(i)} \quad (7)$$

Where

$C_{lab(total)}$ = the total labor cost

$C_{lab(i)}$ = the labor cost of the product element

Environmental impacts

- Energy consumption – The total energy consumed is calculated as follows (Equation 8).

$$E_{total} = \sum_{i=1}^{n} E_{cons(i)} \quad (8)$$

Where

E_{total} = the total energy consumed

$E_{cons(i)}$ = the energy consumed by the product element

- Toxic emission – The total toxic emission is calculated as follows (Equation 9).

$$Toxic_{total} = \sum_{i=1}^{n} Toxic_{(i)} \quad (9)$$

Where

$Toxic_{total}$ = the total toxic emission

$Toxic_{(i)}$ = the toxic emission of the product element

- Recyclability - The global recyclability is calculated as follows (Equation 10).

$$\text{Recyclability} = \frac{\left[\frac{D_d}{5} + \frac{D_s}{5} + \frac{D_r}{5} + E_e\right]}{4} \quad (10)$$

Where

D_d = difficulty of disassembly

D_s = difficulty of separation

D_r = difficulty of recovery

E_r = difficulty of recycling

5.2 *Step 2: generate solutions (processes)*

This step aims to generate solutions, meaning that the manufacturing processes candidate to manufacture the product, are generated. It is created in 2 sub steps: generate all the solutions and reduce the number of solutions.

5.2.1 Generate all the solutions

The individual parts (extracted from the product element set) are selected. Each of them can be produced from different techniques. The manufacturing process of the product is composed of the manufacturing techniques of every individual parts of the product. All the combinations of the part techniques are automatically generated to create the set of all the manufacturing process solutions.

5.2.2 Reduce the number of solutions

All the generated solutions are not valid because some of them fail to meet technical manufacturing and assembly conditions (technical and process conditions) and brand conditions. The techniques are various and lead to different characteristics that meet or not the brand personality. The technical conditions are used to scope the limits of each technique and reduce the conflicts between techniques that make an effect on images and values of products. They mainly come from the experience of expert designers and engineers and are fundamentals for the selection of manufacturing processes. Only the solutions that meet these conditions are kept in the manufacturing process candidate set.

5.3 *Step 3: evaluate the candidates (processes)*

The manufacturing matrix is aggregated in a new one that supports the evaluation of the candidate solutions.

5.4 *Step 4: select the manufacturing process*

The designer decides the most suitable manufacturing process and selects it.

6 Application of the methodology on an industrial case study

This case study was implemented on the design and manufacturing of leather bags in a Thai company. It focused on BSC brand that is an own brand for leather goods. The brand concept of BSC is chic and elegant leather bags for Thai woman. The target customers are between 20-32 years old, and they are working woman with a salary around 15,000-30,000 Baht per month. They also represent the modern woman who lives in the capital and are fashionable and confident. They like to participate to party and social community.

The bag design that was used in this case study was designed for Spring-Summer 2010. The product elements (individual parts) are shown in Figure 8.

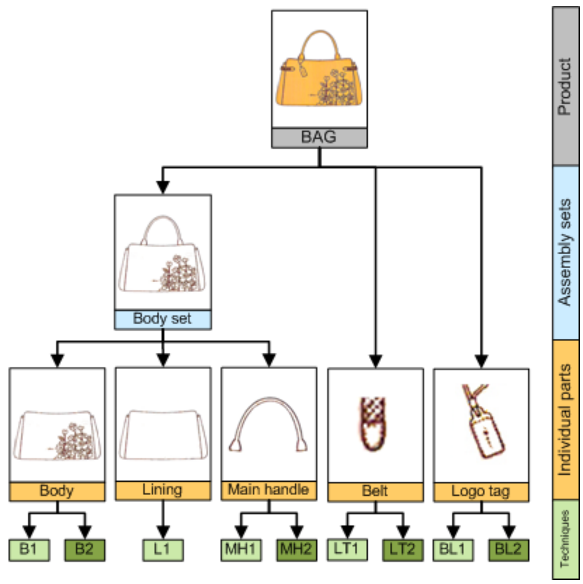

Figure 8: The individual parts of the bag

6.1 *Step 1: create the manufacturing matrix*

The relationship between the manufacturing process steps of each product elements and the process parameters were evaluated and calculated as shown in Figure 9. They were summarized in the manufacturing matrix as shown in Figure 10.

				Process parameters: Machine usage	Raw material area (cm2)	Quality: Soft	Quality: Strong	Quality: Straight	Time (min)	Cost (Baht): Material	Cost (Baht): Labor	Environmental Impacts – Raw Mat.: Water consumption (liter)	Environmental Impacts – Manufacturing: Energy Consumption (kWh)	Environmental Impacts – Manufacturing: Toxic emission (g)	EOL: Dissassembly	EOL: Separate	EOL: Existing recycling process	EOL: Recover
Individual part	Body	B1	Cut leather	yes	2700	4	5	4	5	270	25	25.11	0.0625		3	2	0	2
			Splitting	yes					3		15		0.15					
			Skiving	yes					10		50		0.125					
			printing	no					1		5			28.17				
			gluing	no					2		10			26.67				
			Folding Edge	no					4		20							
			Stitching	yes					5		25		0.0625					
		B2	Cut leather	yes	2504	4	5	5	5	250	25	23.29	0.0625		2	2	0	2
			Splitting	yes					3		15		0.15					
			printing	no					1		5			28.17				
			gluing	no					2		10			26.67				
			Stitching	yes					5		25		0.25					
			Painting	no					3		15			84.51				
	Lining	L1	Cut cotton	yes	2376	4	5	4	0.3	47.5	1.5	14.73	0.04		3	2	0	1
			gluing	no					1		5			13.33				
			Folding Edge	no					2		10							
			Stitching	yes					3		15		0.0375					
	Main handle	MH1	Cut leather	yes	350	4	4	5	1	35	5	3.26	0.0125		2	2	0	2
			Splitting	yes					1		5		0.05					
			Skiving	yes					2		10		0.025					
			gluing	no					1		5			13.33				
			Folding Edge	no					5		25							
			Stitching	yes					3		15		0.0375					
		MH2	Cut leather	yes	250	4	4	5	1	25	5	2.33	0.0125		2	2	0	2
			Splitting	yes					1		5		0.05					
			gluing	no					1		5			13.33				
			Stitching	yes					3		15		0.0375					
			Painting	no					3		15			84.51				
	Belt	BL1	Cut leather	yes	130	3	4	4	1	13	5	1.21	0.0125		2	2	0	3
			Splitting	yes					1		5		0.05					
			Skiving	yes					1		5		0.0125					
			gluing	no					1		5			13.33				
			Folding Edge	no					1		5							
			Stitching	yes					2		10		0.025					
		BL2	Cut leather	yes	75	4	3	4	1	7.5	5	0.70	0.0125		2	2	0	3
			Splitting	yes					1		5		0.05					
			gluing	no					1		5			13.33				
			Stitching	yes					1		5		0.0125					
			Painting	no					3		15			84.51				
	Logo tag	LT1	Cut leather	yes	70	4	5	4	1	7	5	0.65	0.0125		3	2	0	2
			Splitting	yes					1		5		0.05					
			Skiving	yes					2		10		0.025					
			Stamping	yes					1		5		0.04167					
			gluing	no					1		5			13.33				
			Folding Edge	no					2		10							
			Stitching	yes					2		10		0.025					
		LT2	Cut leather	yes	30	4	5	5	1	3	5	0.28	0.0125		2	2	0	2
			Splitting	yes					1		5		0.05					
			Stamping	yes					1		5		0.04167					
			gluing	no					1		5			13.33				
			Stitching	yes					2		10		0.025					
			Painting	no					3		15			84.51				
Assembly set	Body set 1	B1+L1+MH1	gluing	no		4	5	5	1		5			13.33	2	2	0	2
			Folding Edge	no					1		5							
			Stitching	yes					5		25		0.0625					
	Body set 2	B2+L2+MH2	gluing	no		4	5	5	1		5			13.33	2	2	0	2
			Stitching	yes					5		25		0.0625					
			Painting	no					2		10			56.34				
	Final 1	Body set 1+BL1+LT1	Stitching	yes		4	5	4	1		5		0.0125		4	2	0	2
			Fastening	no					0.5		2.5							
	Final 2	Body set 2+BL2+LT2	Stitching	yes		4	5	4	1		5		0.0125		4	2	0	2
			Fastening	no					0.5		2.5							

Figure 9: The parameters of the manufacturing process steps of the leather bag elements

				Process parameters									
				Quality				Cost (Baht)		Environmental Impacts			
										Raw Mat.	Manufacturing		EOL
				Soft	Strong	Straight	Time (min)	Material	Labor	Water consumption (liter)	Energy Consumption (kWh)	Toxic emission (g)	Recyclability
Product elements	Individual part	Body	B1	4	5	4	30	270	150	25.11	0.4000	54.84	1.75
			B2	4	5	5	19	250	95	23.29	0.4625	139.35	1.5
		Lining	L1	4	5	4	6.3	47.5	31.5	14.73	0.0775	13.33	1.5
		Main handle	MH1	4	4	5	13	35	65	3.26	0.1250	13.33	1.5
			MH2	4	4	5	9	25	45	2.33	0.1000	97.85	1.5
		Belt	BL1	3	4	4	7	13	35	1.21	0.1000	13.33	1.75
			BL2	4	3	4	7	7.5	50	0.70	0.0750	97.85	1.75
		Logo tag	LT1	4	5	4	10	7	50	0.65	0.1542	13.33	1.75
			LT2	4	3	4	9	3	45	0.28	0.1292	97.85	1.5
	Assembly set	Body set 1	B1+L1+MH1	4	5	5	7		35		0.0625	13.33	1.5
		Body set 2	B2+L2+MH2	4	5	5	8		40		0.0625	69.68	1.5
		Final 1	Body set 2+BL1+LT1	4	5	4	1.5		7.5		0.0125		2
		Final 2	Body set 1+BL2+LT2	4	5	4	1.5		7.5		0.0125		2

Figure 10: The manufacturing matrix

6.2 *Step 2: generate solutions (processes)*

The product elements (Figure 8) are combined to generate the manufacturing process solution set. Sixteen initial solutions were generated (Figure 11).

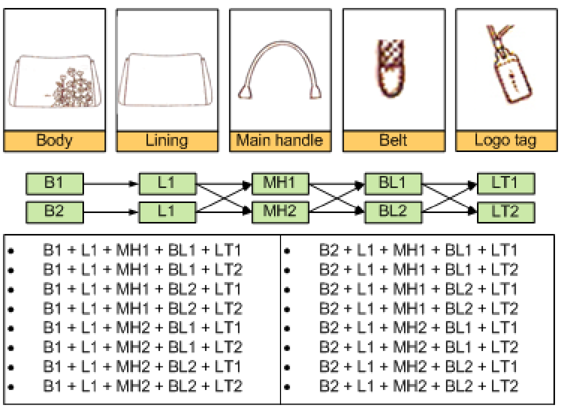

Figure 11: The sixteen initial solutions

The set of solutions was reduced by using the technical conditions embedded in the manufacturing database. The folding and painting edge techniques are technical conditions that were used to reduce the initial solutions. They are exclusive within a single bag. Folding edge technique is more manufacturing time consuming because it needs to fold the edge before stitching (sewing). Painting edge technique is a very easy technique because it does not need to fold the edge that leads to a lower manufacturing cost. Both techniques express the images and values of the product: Folding edge techniques sounds "official" and "formal"; Painting edge technique "casual" and "comfortable". Thus, both techniques cannot be used in the same bag.

B1, MH1, BL1 and LT1 are product elements that were produced from the folding edge technique. B2, MH2, BL2 and LT2 are product elements that were produced from the painting edge technique. L1 is lining (inside material) that was produced from the folding edge technique. It can be used for both the folding and painting edge technique. The belt and logo tag are the special product elements used to decorate the bag. They have to be produced from the same technique. Then, the belt and logo tab, which were produced from the painting edge, can be combined with other product elements that were produced from the folding edge technique.

Thus, the solutions were finally reduced from 16 to 3 solutions as shown in Figure 12.

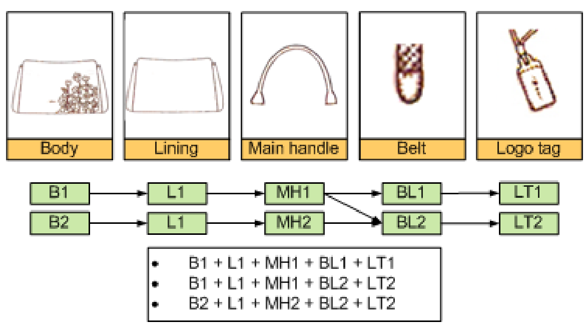

Figure 12: The three final solutions

6.3 *Step 3: evaluate the candidates (processes)*

The data from the manufacturing matrix are aggregated to summarize the values of each solution (Figure 13)

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		Quality				Cost (Baht)		Environmental Impacts			
								Raw Mat.	Manufacturing		EOL
	Solution	Soft	Strong	Straight	Time (min)	Material	Labor	water consumption (litre)	Energy consumption (kWh)	Toxic emission (g)	Recyclability
1	B1 + L1 + MH1 + BL1 + LT1 + Body set 1 + Final 1	3.86	4.71	4.29	75	373	374	44.96	0.93	121.50	1.68
2	B1 + L1 + MH1 + BL2 + LT2 + Body set 1 + Final 1	4.00	4.29	4.29	74	363	384	44.07	0.88	290.53	1.64
3	B2 + L1 + MH2 + BL2 + LT2 + Body set 2 + Final 2	4.00	4.29	4.43	60	333	314	41.32	0.92	515.90	1.61

Figure 13: The summarized values of each solution

6.4 *Step 4: select the manufacturing process*

From Figure 13, solution 3 was the most suitable solution when the focus is on quality, time and cost. The values are lower than those of the other solutions. From the environmental impact point of view, the water consumption, energy consumption and recyclability of solution 3 are not different to the other solutions except the toxic emission. This solution releases lot of toxic (515.9 g), which gets harmful effects on workers. It was decided to reject solution 3 due to the bad environment impact. Solution 1 was proposed to be the suitable solution, although the manufacturing time (75 min.), the water consumption (44.96 liter) and the energy consumption (0.93 kWh) were more than solution 2. This case study, the toxic criterion (health of workers) was emphasized by designers and engineers. Then, the suitable solution depends on decision of designers and engineers.

7 Conclusions

This study proposed a decision method to help designers and engineers select manufacturing processes that ensure the expected performance, including friendly with the environment. The methodology was structured and supported by a matrix called the manufacturing matrix. The methodology was implemented and tested on an original case in a Thai company. It had shown that this methodology was necessary to provide a lot of manufacturing data to support the selection of the manufacturing process. Extracting all data was a huge work but finally not so difficult because production engineers used to formalize their data. Finally, this methodology that seemed to be very automatic was not so automated and designers had to participate with the production engineers, experts or workers, who well knew the manufacturing processes to acquire alternatives. We conclude that the methodology is able to help practically designers and engineers select the suitable manufacturing process.

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