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Make or Buy Analysis Model Based on Tolerance Design to Minimize Manufacturing Cost and Quality Loss

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Abstract

In a manufacturing company, manufacturing costs, or component prices, and tolerance will affect the price and the quality of a product. Companies must produce high-quality products with low manufacturing costs in order to keep their products competitive in the market; however, it is difficult to produce a high-quality product with a low manufacturing cost. Companies have difficulties in determining the components to be produced using their own manufacturing facilities (make) or outsourced to their suppliers (buy). Hence, a make or buy analysis is needed to minimize the manufacturing costs and quality loss and to determine the optimum alternative regarding make or buy decisions. This paper discusses an optimization model of a make or buy analysis for a manufacturing company in order to minimize the manufacturing costs and the quality loss in terms of manufacturer and customer quality loss. A numerical example is provided to show the application of the model using a simple assembly product consisting of three components. There are two machines that can be used to produce the components and three alternatives of suppliers to fulfill the order. Each machine and supplier have different characteristics in terms of manufacturing costs and its tolerance.

Abstrak

Model Make or Buy Analysis Berbasis Perancangan Toleransi untuk Meminimumkan Biaya Manufaktur dan Kerugian Kualitas. Pada sebuah perusahaan manufaktur, biaya manufaktur, atau harga komponen dan toleransinya akan mempengaruhi harga jual dan kualitas sebuah produk. Karena itu, perusahaan harus dapat menghasilkan produk berkualitas tinggi dengan biaya manufaktur yang rendah untuk menjaga agar produk tersebut tetap kompetitif di pasaran. Perusahaan mengalami kesulitan dalam menentukan komponen mana yang harus diproduksi menggunakan fasilitas yang dimiliki sendiri dan mana yang harus di-*outsource* kepada pemasok. Karena itu, *make or buy analysis* dibutuhkan untuk meminimumkan biaya manufaktur dan kerugian kualitas dan menentukan pilihan yang optimal berkaitan dengan keputusan melakukan produksi sendiri atau membeli komponen dari pemasok. Makalah ini membahas sebuah model optimisasi *make or buy analysis* untuk meminimumkan biaya manufaktur dan kerugian kualitas dalam bentuk kerugian kualitas yang ditanggung perusahaan maupun pelanggan. Contoh numerik diberikan untuk menunjukkan aplikasi model menggunakan sebuah rakitan sederhana yang terdiri atas tiga komponen. Terdapat dua mesin yang dapat digunakan untuk menghasilkan komponen-komponen tersebut dan tiga pemasok untuk memenuhi permintaan. Setiap mesin dan pemasok memiliki karakteristik yang berbeda dalam hal biaya manufaktur dan toleransi yang dapat dihasilkan.

Keywords: *make or buy analysis, manufacturing cost, optimization, quality loss, tolerance*

1. Introduction

In a manufacturing company, manufacturing costs and quality loss must be considered by the company to remain competitive in the market. The company has two alternatives in producing the components: use its own manufacturing facilities or outsource to its suppliers. Hence, the company must perform a make or buy analysis to minimize the costs. Several factors affect

make or buy decisions. Process capability and production capacity are two determining factors that affect the decision. The capability process of production facilities has a strong relationship with the component tolerances. The tolerances will determine the manufacturing costs and the quality loss.

Outsourcing causes the company to rely on suppliers to compete with its competitors [1]. In outsourcing,

components are bought from suppliers, and then the component prices influence the final price of the product [2,3]. In addition, outsourcing can help companies focus on their core business [4]. Therefore, a manufacturing company must be very careful in determining whether the component is made in-house (make), purchased from suppliers (buy), or a combination of both. The right decisions and policies will determine the success of the business [1], which is why the make or buy analysis becomes an important aspect in a manufacturing company.

In the decision to make the components, the process selection is very important for companies because the selection will be influenced by the tolerance of the components, which will influence the manufacturing costs and the quality loss [5]. Loose tolerances will result in lower manufacturing costs but higher quality loss than tight tolerances [2]. In this study, we consider two quality losses: manufacturer and customer quality losses. Manufacturer quality loss involves scrap and rework costs [6]. We used the Taguchi Quality Loss function to measure the customer quality loss because this function has been used by many researchers [3-5,9].

Outsourcing has several advantages. According to Accenture Consulting [7], 50% of savings in the procurement cost of outsourcing activities will influence 30% of total corporate savings. Moreover, most of the quality experts agreed that the main problems in outsourcing activities are the quality and the variability of supplied materials that will be used in manufacturing processes and in assembly [3]. The non-conformance in materials and components that are supplied by suppliers is responsible for more than 50% of manufacturing costs [8]. Hence, supplier selection is a difficult and critical task that takes time [9]. Selecting an inappropriate supplier leads to an intangible loss after products reach the consumer. Intangible losses are difficult to assess because they have different effects ranging from the loss of a customer's trust to the decrease of the reputation of the company [3,7,9].

The allocation is the next important decision. The allocation of components to the selected processes or suppliers not only depends on the production capacity of the selected processes or suppliers but also their process capabilities. Hence, we consider the combined decision to both make and buy and allow for more than one process or supplier to be selected, which allows the company to have more flexibility in the allocation process and have an opportunity to be more efficient in the allocation.

The aim of this research is to develop an optimization model that can be used to aid a decision maker in performing a make or buy analysis and allocating the components to the selected processes or suppliers. The

rest of this paper is organized in five sections. In the next section, we will describe the research method. Sections 3 and Section 4 discuss the model development and the numerical example and analysis, respectively. In the last section, we provide the conclusions and suggestions for future research.

2. Methods

The make or buy analysis is an analysis to determine the optimum decisions concerning in-house production or outsourcing, a combination between both in-house production and outsourcing, and the allocations to the selected processes or suppliers. In this study, we consider the system as shown in Figure 1.

Figure 1 illustrates that each component that will be needed in the assembly of a product has the same options in the make or buy analysis. For the decision to make a component, the component can be manufactured using several processes. Each process has its own manufacturing costs and process capabilities. Assuming that each component is manufactured using a single process, a machine represents single process. For the decision to buy a component, each supplier has the same opportunity to supply the components. Each supplier offers a different price based on the quality of the component. We assume that the quality of a component is represented by its tolerance. Suppliers offer a higher price for a component with a tighter tolerance than a looser tolerance because they must manufacture the component using more precise machines and the production time is longer.

The optimization model presented in this paper is used to select one or more of the alternative machines (make) and suppliers (buy) to produce each component and to determine the production/order allocation of the selected alternatives to obtain the optimum decisions. The decision variables in this model are the machines (b_{im}), the suppliers (b_{ij}), and the component allocations (x_{ij} and y_{im}).

The following notations are used in this research:

i	:component index
j	:supplier index
k	:manufacturing stages index
m	:machine index
b_{ij}	:binary number for component i supplied by supplier j
b_{im}	:binary number for component i manufactured by machine m
c_{ij}	:purchased price of component i supplied by supplier j
k_{ij}	:production capacity of component i in supplier j
k_{im}	:production capacity of component i at machine m

x_{ij}	:amount of component i ordered to supplier j
y_{im}	:amount of component i manufactured in machine m
A	:cost coefficient of quality loss
D	:demand of final product
Cp	:process capability index
$E(S)$:expected proportion of scrap in assembly process
M_{im}	:manufacturing cost for component i in machine m
Sc	:scrap cost per unit product
Q	:total quality loss
TC	:expected total cost
T_A	:assembly tolerance limit of k -th dimensional chain
$\partial R/\partial x_i$:partial derivative equation of component i functional dimension
σ_{ij}^2	:variance of component i supplied by supplier j
σ_{im}^2	:variance of component i manufactured in machine m
σ_A^2	:variance of assemblies of the k -th dimensional chain

3. Results and Discussion

Model development. Each alternative supplier that supplies component i for the assembly produces a product dimensional variance of σ_{ij}^2 . Each alternative machine for component i produces components with a dimensional variance of σ_{im}^2 . Assembly tolerance specification limits must be included in the model, and the total component variance must not exceed the assembly dimensional tolerance of σ_A^2 . The manufacturing cost of component i on machine m is denoted by c_{im} , while the offering price of component i from supplier j is denoted by c_{ij} .

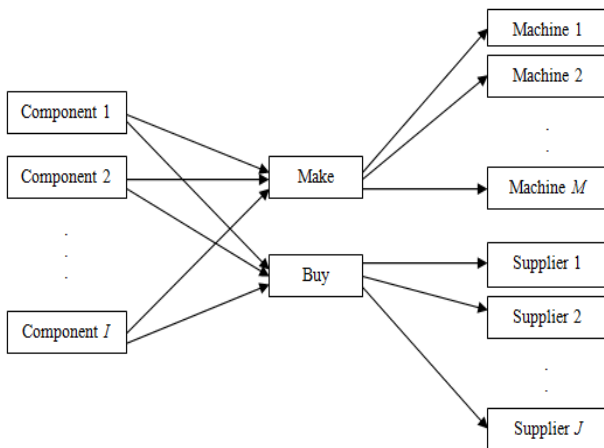


Figure 1. System Description

The number of components must be able to fulfill the customer orders (D). The number of components produced on each machine must not exceed the production capacity. There is also a maximum production capacity for each supplier. The assembly process will result in scrap, which is the assembly that is beyond the specification limits. The total quality loss consists of manufacturer and customer quality loss. The manufacturer quality loss in this study is assembly scrap, which is determined by multiplying the proportion of scrap, the level of demand, and the cost per unit of scrap.

The scrap proportion can be calculated using the following equation:

$$E(S) = 1 - \int_{LSL}^{USL} f(x) dx \quad (1)$$

In Equation (1), $f(x)$ is the probability distribution function of an assembly. LSL and USL denote lower specification and upper specification limits, respectively. The customer quality loss is measured using the Taguchi loss function, which can be expressed in terms of assembly bias and variance. We assume that the process mean is equal to the target nominal value, so the bias is zero. The objective function of the optimization model is formulated using non-linear integer programming. Equation (2) expresses the objective function, which consists of manufacturing/purchasing costs, customer quality loss, and manufacturer quality loss.

$$\text{Min TC} = \sum_{i=1}^I \left(\sum_{m=1}^M (M_{im} x_{im} b_{im}) + \sum_{j=1}^J (c_{ij} y_{ij} b_{ij}) \right) + \frac{A}{T_A^2} \sigma_A^2 + D(E(S)) S_c \quad (2)$$

Four constraints are considered for this research: maximum assembly tolerance, production/supplier capacity, the amount of components to fulfill the final product demand, and the minimum selected process/supplier.

Component and assembly tolerance. This constraint is necessary to ensure the quality of the assembly results. The quality is represented by product tolerance in which a product will be considered to be defective when the resulting assembly tolerance exceeds the product tolerance. We used combined variance as suggested by Oshungade [10] to represent the variance of each component from the different sources. Equation (3) shows the formulae to find the combined variance of each component i . The resulting variance of assembly can be expressed in Equation (4) as a linear combination of component variances.

$$\sigma_i^2 = \frac{\sum_{m=1}^M \left(\frac{t_{im}}{3Cp} \right)^2 x_{im} + \sum_{j=1}^J \left(\frac{t_{ij}}{3Cp} \right)^2 y_{ij}}{x_{im} + y_{ij}} \quad (3)$$

$$\sigma_A^2 = \sum_{i=1}^I \sigma_i^2 \quad (4)$$

Production/supplier capacity constraint. Capacity constraint is used to ensure that the allocated amount of of components will not exceed the machine/supplier capacity. If a machine/supplier is selected and there is still an amount of components that have not been allocated yet, then the remaining components will be allocated to another process/supplier. Equations (5) and (6) express the constraints for suppliers and process capacity, respectively.

$$\sum_{i=1}^I x_{im} b_{im} < k_m, \quad \forall m \quad (5)$$

$$y_{ij} b_{ij} < k_{ij} \quad (6)$$

Product demand constraint. In order to meet the final product demand, the components allocated to the selected processes/suppliers must be multiplied by the amount of components needed to assemble one unit of a final product. Equation (7) expresses the constraint.

$$\sum_{m=1}^M x_{im} b_{im} + \sum_{j=1}^J y_{ij} b_{ij} = D_i, \quad \forall i \quad (7)$$

Minimum number of selected process/supplier. This constraint indicates that there is at least one selected process and/or supplier for each component to ensure the availability of each component.

$$\sum_{m=1}^M b_{im} + \sum_{j=1}^J b_{ij} \geq 1, \quad \forall i \quad (8)$$

Binary constraint. This constraint is used to represent the selection process (0 if not selected and 1 if selected). Equations (9) and (10) are used to represent the selection of the process and the supplier, respectively.

$$b_{im} \in [0,1] \quad (9)$$

$$b_{ij} \in [0,1] \quad (10)$$

Equations (11) and (12) ensure that all of the necessary components are produced or purchased from the available processes or suppliers.

$$y_{im} \geq 0 \quad (11)$$

$$x_{ij} \geq 0 \quad (12)$$

Numerical example and analysis. A numerical example is provided to demonstrate the application of

the model. We use the case of assembly in [3] because the assembly is simple and representative to show the implementation of the model. Figure 2 shows the assembly, which consists of three components: C_1 , C_2 , and C_3 . The critical dimension is h in which the dimension is $h = 60.000 \pm 0.025$ mm. The dimensions of each component of C_1 , C_2 , and C_3 are assumed to be normally distributed with the mean of $\mu_1 = 10.000$ mm, $\mu_2 = 20.000$ mm, and $\mu_3 = 30.000$ mm.

We assume that the mean is equal to the target value of the components. The in-house processes and the suppliers have the same opportunity to meet the demand of the components. Each machine and supplier have different characteristics in terms of manufacturing costs and component tolerance. Table 1 shows the manufacturing cost data and the resulting tolerance for each component i that are supplied by suppliers.

The company received an order of 300 units of final product. The capacity of Machine 1 and Machine 2 are both 250 units as shown in Table 2. In the numerical example, it is assumed that all machines have the same process capability indices of $Cp=1$ for each component. The suppliers' and the machines' capacity is presented in Table 3. The cost coefficient of quality loss is assumed to be IDR 150,000 with the scrapped cost being IDR 200,000 per unit. The costs are determined by the loss of customer and manufacturer when the product is failure.

We used Crystal Ball software to solve the model. The optimization results are shown in Table 4. From the results of the optimization, Component 1 must be manufactured using Machine 2 and supplied by Supplier 2 in the amount of 200 and 100 units, respectively. Component 2 is manufactured by Machine 1 and supplied by Suppliers 2 and 3 in the amount of 50, 100, and 150 unit components, respectively. Component 3 must be manufactured by Machine 1 and supplied by Supplier 1 in the amount of 175 and 125 unit components, respectively. The optimization results in the manufacturing and purchasing costs of IDR 4,300,000 and IDR 6,212,500, respectively. The internal and customer quality losses are IDR 199,004.87 and IDR 9,333.33, respectively. The total cost for the optimization results is IDR 10,720,838.20.

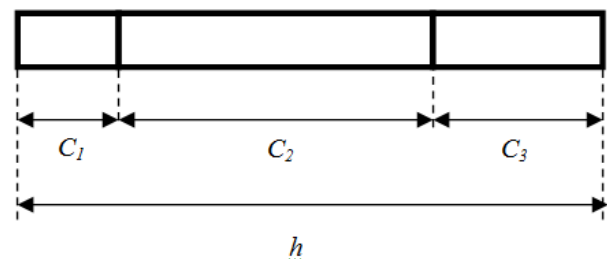


Figure 2. Simple Assembly (Adapted from Feng et al. [3])

Table 1. Manufacturing Cost and the Respective Component Tolerance for Each Machine

Machine	Component 1		Component 2		Component 3	
	Tolerance (mm)	Cost (IDR)	Tolerance(mm)	Cost (IDR)	Tolerance (mm)	Cost (IDR)
1	0.010	10,000	0.005	17,500	0.010	11,000
2	0.015	7,500	0.005	17,500	0.005	12,000

Table 2. Price and the Respective Component Tolerance for Each Supplier

Supplier	Component 1		Component 2		Component 3	
	Tolerance (mm)	Price (IDR)	Tolerance(mm)	Price (IDR)	Tolerance (mm)	Price (IDR)
1	0.010	9,000	0.005	18,000	0.010	10,500
2	0.015	7,000	0.005	16,500	0.005	12,500
3	0.010	11,000	0.005	17,000	0.010	11,000

Table 3. Production Capacity for Each Supplier and Machine

	Supplier 1	Supplier 2	Supplier 3	Machine 1	Machine 2
Component 1	100	100	100	200	200
Component 2	100	100	150	200	200
Component 3	125	125	100	250	250

Table 4. Optimization Results

	Supplier 1	Supplier 2	Supplier 3	Machine 1	Machine 2
Component 1	0	100	0	0	200
Component 2	0	100	150	50	0
Component 3	125	0	0	175	0

4. Conclusions

In this paper, we present an optimization model that can be used to make decisions concerning the make or buy analysis. The model can also be used to determine the optimal component tolerances while taking into consideration the upper tolerance limit of the assembly. We considered two decisions in this make or buy analysis model, which are process/supplier selection and product allocation to the selected process/supplier. The objective function of the model is to minimize manufacturing costs and quality loss for both manufacturer loss due to scrapped assembly products and customer quality loss. The optimal solutions are achieved by selecting the least total cost which consists of manufacturing cost and quality loss. In future research, this model can be expanded by incorporating fuzzy quality loss and a multi-stage manufacturing process.

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