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## PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

# A concurrent optimization model for suppliers selection, tolerance and component allocation with fuzzy quality loss

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**Abstract:** The aim of this paper is to develop an optimization model to optimally select suppliers and allocate components to the selected suppliers. The objective function of the model is to minimize purchasing cost and fuzzy quality loss. Using fuzzy quality loss, the assembly quality may be divided into several grades allowing the fuzziness in the resulted assembly tolerance. The model considers several constraints such as production capacity, assembly quality, and process and technological capability of the suppliers. A numerical example is given in this paper to show the implementation of the model. Sensitivity analysis is performed to determine the effect of process capability to the supplier selection, components allocation and total cost. The increase of process capability in one of the suppliers affects the selection and component allocation mainly when the process capability increase from 1 to 1.5. Further, increasing the process capability index to 2 has no effect on the selection and allocation but affects the fuzzy quality loss and hence reduces the total cost.

**Subjects:** Industrial Engineering & Manufacturing; Production Engineering; Systems & Control Engineering

**Keywords:** concurrent optimization; supplier selection; tolerance design; component allocation; fuzzy quality loss

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### PUBLIC INTEREST STATEMENT

Outsourcing is a common practice in today's manufacturing systems. A manufacturing company usually has several suppliers to help the company in providing the needed components for their final product. Selecting appropriate suppliers will give many benefits to the company so the suppliers selection must be performed carefully. Concurrent engineering has allowed a company to make simultaneous decisions concerning product design and manufacturing. This paper used concurrent engineering approach to make decisions about supplier selection, tolerance allocation and component allocation to the selected suppliers which will optimally minimize the total cost comprising of purchasing cost and fuzzy quality loss. The used of fuzzy concept in this paper allowed us to group the final product into several grades according to the resulted assembly tolerance.

## 1. Introduction

A product may consist of many components. The capability and production capacity of a company will constraint the ability of the company in producing the components. There are two types of capabilities which constraining the company's ability, namely technological and process capability (Rosyidi, Jauhari, & Sabatini, 2013). Technological capability is the capability of supplier in producing certain types of components. This capability will depend on the availability of production and process facilities, skill and manpower, customized services, and cost evaluation (Sarode, Sunnapwar, & Khodke, 2008). Process capability is a measure which frequently used to evaluate whether a product or a process can meet a customer's requirements (Montgomery, 2001). The capacity deals with the ability of the company in meeting the demand and will depend on the number of certain types of machines or production facilities. Technological capability, process capability, and production capacity constraints will lead to three alternatives in providing the components for an assembly product. First, the components are provided by the company using its own machines or production facilities (in-house production). This alternative can be selected if the company has enough capability and capacity in producing the components. Second, the company outsources all the needed components to the suppliers. This method is conducted in a company which does not have capability and capacity in producing the components. Third, the company produces some of the needed components in-house and some others are outsourced to the suppliers. This method is conducted in a company which has enough capability but not enough capacity in producing such components.

The outsourcing gives many benefits to the company such as reducing production cost, doubling before tax income, increasing performance, and helping company to be more focus to its core business (Barthelemy, 2003). The main problems in outsourcing activities are the quality and variability of the components resulted from the suppliers. Hence suppliers selection is a difficult and time-consuming task since each supplier offers a component with different quality and price. The other problem concerns with the allocation of the components to the selected suppliers. The company has to select suppliers such that the accumulation of component tolerance may not exceed the assembly tolerance which set to maintain the quality of the final product while in the same time minimizing the purchasing cost. The problem arises from the fact that the tighter the component tolerance, the higher the price offered by supplier. This is logical since suppliers have to use more precise equipment in producing the components with tighter tolerance resulting better quality components while in the other side it will rise their production cost.

Product quality is one of important factors for a succesfull product in the market. Hence, quality is a critical concern for most manufacturers and the need for high-quality suppliers has always been an important issue for many manufacturing organizations (Pi & Low, 2006). Beside quality, purchasing price of components from suppliers is widely used factor in supplier selection. In this research, we attempt to simultaneously address supplier selection, tolerance allocation and the allocation of the components to the selected suppliers. The model considers process and technological capability and production capacity of the suppliers to minimize purchasing cost and fuzzy quality loss .

The rest of this paper is organized as follows. In Section 2, the related research are reviewed. Sections 3 and 4 deal with model development and numerical example and analysis respectively. The conclusions and direction for future research are given in Section 5.

## 2. Literature review

Supplier selection has gained attentions from many researchers. Linn, Tsung, and Ellis (2006) developed a methodology in supplier selection using process capability and price analysis. They used a chart which partitioned to group the suppliers into several zones according to their quality performances and price levels. Rajan, Ganesh, and Narayanan (2010) developed a supplier selection model to maximizing weights. The weight of each criteria is derived using analytic hierarchy process (AHP). The model considered technological capability, allowed more than one suppliers to be selected, and the total number of suppliers for all products. Pi and Low (2006) used Taguchi loss function and AHP

in supplier selection. Taguchi loss function was used to measure the loss in the criteria (quality, on-time delivery, price, and service), while AHP was used to determine the weight of each criteria.

Nukala and Gupta (2007) developed a multi-objective optimization model for suppliers selection. The research considered closed loop supply chain network and used Taguchi loss function to measure the quality of the product. Teeravaraprug (2008) developed an optimization model for selecting suppliers using Taguchi loss function. Taguchi loss function is the most widely used function to measure the external quality cost. In Taguchi quality loss, the loss is measured by deviation of mean performance from its target value and the variance of performance level. The research used purchasing cost along with four loss functions, quality loss, loss of speed, dependent, and flexibility. Taguchi loss function has also been widely used as a criteria in tolerance design research in an addition to manufacturing cost. Tolerance is a limit of dimension variation towards a nominal value. Tolerance is determined to control both the allowable variations of components and assemblies. There are two common approaches in tolerance design, which are tolerance synthesis or allocation and tolerance analysis. Tolerance allocation starts with assembly tolerance and then allocates the assembly tolerance to the component tolerance, while tolerance analysis tries to estimate the assembly tolerance based on components tolerances. Typically, tolerance design can be modeled in two ways, continuous and discrete. In continuous model, manufacturing cost was constructed using cost-tolerance relationship function while in discrete model, tolerance design was constructed as process or supplier selection problem.

Chase, Greenwood, Loosli, and Hauglund (1990) is considered as the early researcher in discrete tolerance model which try to determine the optimal tolerances by process selection to minimize the manufacturing cost. In another context, Feng, Wang, and dan Wang (2000) developed a discrete optimization model to concurrently select the optimal supplier and tolerance. The objective of the model was to minimize purchasing cost and quality loss. The model allowed only one supplier is selected. Sabatini, Jauhari, and Rosyidi (2011) developed an optimization model by relaxing the research of Feng et al. (2000) to allow more than one suppliers can be selected. The relaxation of the constraint is conducted through changing the equation into in-equation and adding one constraint, namely the minimum required number of suppliers. The other constraint imposed in the model of Sabatini et al. (2011) is the technological capability which represents the ability of suppliers in manufacturing certain types of components.

All the above research only deal with suppliers selection both in the context of multicriteria decision and tolerance design. There is another important decision following the suppliers selection, namely order allocation to the selected suppliers. Ghorbeni, Bahrami, and Arabzad (2012) developed a two-phased model in supplier selection and order allocation. In the first phase, the supplier is selected by several criteria which defined using SWOT analysis and the weight is determined using Shannon's Entropy. The order allocation is determined consecutively using integer linear programming (ILP). Fors, Harraz, and Abouli (2011) also developed a two-phased model in supplier selection and order allocation. In the first phase, supplier pre-selection was conducted using several criteria. The suppliers were sorted by calculating a metric which measured by Euclidean distance between two vectors. This first phase resulted in a shortlist of suppliers which helps decision-maker to efficiently collect detailed data about shortlisted suppliers with minimum efforts in the second phase. In the second phase, an optimization model was developed to select suppliers and allocate the order to the selected suppliers. The objective function of the model was to minimize a total cost comprising of delivery cost, quality cost, and purchasing cost. Sodenkamp and Suhl (2012) discussed a multicriteria multilevel group decision to facilitate making supplier selection decisions and improves the quality of order allocations. The order allocation was done by simply proportional to the normalized weight of the selected alternatives.

The decision-making in engineering problems is often made under uncertainty situations due to the limited data and information. The uncertainty situation is one of the real world characteristics (Guner & Kuzu, 2009). All engineering uncertainties can be categorized as aleatory and epistemic

uncertainty (Youn, 2005). The aleatory is uncertainty with sufficient statistical information while epistemic is uncertainty with lack of statistical information. Fuzzy deals with the epistemic uncertainty and has been applied in many engineering problems. Fuzzy was introduced by Zadeh (1965) and takes into account the human subjectivity in decision-making due to linguistic variables which allows precise modeling of imprecise statements (Kahraman, Ertay, & Buyukozkan, 2006). There are many researches have been conducted in supplier selection in fuzzy environment. For example, Bayrak, Çelebi, and Taşkin (2007) proposed fuzzy preference index to select the best supplier. A case study in supplier selection using fuzzy approach in just in time production system has been conducted by Guneri and Kuzu (2009).

Cao, Mao, Yang, Wu, and Wu (2006), Cao, Mao, Ching, and dan Yang (2009) introduced fuzzy quality loss in a robust optimization model to determine the optimal tolerance of an assembly. The objective function of the model is to minimize manufacturing cost and fuzzy quality loss. The research used the fuzzy quality loss to group the product into several grades based on the dimension of the resulted assembly. Fuzzy quality loss represents the quality characteristic levels of the assembled product and group the product into several grades in which each grade is determined qualitatively. Hence the assembled product not only contains good or poor quality (classical set theory) but also contains several quality levels that can be determined by fuzzy theory. Hsieh (2007) proposed a fuzzy application to improve the quality of qualitative quality response. The research used the fuzzy set theory to group the response into several grades. Chen, Tzeng, Hsu, and Chen (2010) proposed fuzzy logic in tolerance design of a dual six-bar mechanism. The fuzzy logic in that research was combined with Taguchi method and principal component analysis and used to derive the multiple performance index from the result of experiment. Stella and Alena (2012) developed an application of fuzzy principles in evaluating quality of manufacturing process using Matlab. The fuzzy is used to represent the uncertainty in process capability and simulation is conducted to determine the quality of the final product.

The introduction of concurrent engineering has shifted the paradigm from serial product development to simultaneous product development. In the later approach, decision-making is made simultaneously by considering many aspects of engineering, productions and supply chain in early product design and development stage. An important decision-making in product design and development, especially in detail design phase is set the product tolerance and assign the tolerance to its components. Hence, the decision about tolerance design can be conducted simultaneously with suppliers selection and allocate the components to the selected suppliers.

### 3. Model development

We consider a company which outsource all of the needed components and to assemble all the components into the final product. The company has several suppliers in which each supplier has its own capability and capacity. Each supplier offers components with different prices and qualities. The ability of the suppliers in supplying the components are constrained by their process and technological capabilities and production capacities. The company has a number of demand and imposes a product specification (tolerance) to the final product as the quality requirement. The company must make a decision concerning suppliers selection, tolerance allocation, and allocating the components to the selected suppliers by types and quantities. The process capability will determine the quality and price of the components. The tighter the component tolerance, the higher the price offered by suppliers. This type of capability depends on the precision of the production facilities. More precise production facilities will result in tighter tolerance, and adversely will lead to the higher prices. The technological capability will determine the capability of the suppliers in producing many types of components. This capability will depend on the type of production facilities owned by suppliers. The production capacity will determine the ability of the suppliers in producing the number of components.

### 3.1. The objective function

The objective function of the model is to minimize purchasing cost and fuzzy quality loss. Equation (1) expresses the purchasing cost, while the quality loss is expressed in Equation (2).

$$MC = \sum_{i=1}^I \sum_{j=1}^J c_{ij} x_{ij} y_{ij} \tag{1}$$

where  $c_{ij}$  is purchasing cost of component  $i$  which supplied by supplier  $j$ ,  $x_{ij}$  is binary variable, 1 if the supplier is selected and 0 otherwise,  $y_{ij}$  is quantity of component  $i$  which purchase by company from supplier  $j$ .

$$FQL = \sum_{g=1}^G R_g L_g \tag{2}$$

where  $R_g$  is probability of component at quality level  $g$ ,  $L_g$  is quality loss of component at quality level  $g$ .

In Equation (2), the probability of component at quality level  $g$  can be determined from the comparison of the expected component at quality level  $g$  with the total number of assembly product. The function for the probability can be seen in Equation (3):

$$R_g = \frac{r_g}{\sum_{p=1}^P r_p} \tag{3}$$

The expression for the numerator of Equation (3) can be seen in Equation (4). In this equation,  $\mu_g$  denotes the subject function of quality characteristic  $h$  at quality level  $g$ , while  $f(h)$  denotes the probability density function of quality characteristic  $h$  which is assumed to follow normal distribution. The expression of the normal distribution in this research is shown in Equation (5). In Equation (5),  $\sigma_a$  denotes the deviation standard of the resulted assembly. The resulted deviation standard of the assembly will depend on the tolerance of the components purchased from the supplier:

$$r_g = \int_{-\infty}^{\infty} \mu_g(h) f(h) dh \tag{4}$$

$$f(h) = \frac{1}{\sigma_a \sqrt{2\pi}} e^{-\frac{1}{2} \left( \frac{h-\mu}{\sigma_a} \right)^2} \tag{5}$$

Equation (6) shows the expression for the deviation standard of the resulted assembly:

$$\sigma_a = \frac{1}{3Cp} \sqrt{\sum_{i=1}^I \sum_{j=1}^J \left( \frac{\partial f(t)}{\partial t} (t_{ij}) \right)^2 x_{ij}} \tag{6}$$

where  $\frac{\partial f(t)}{\partial t}$  is the sensitivity of assembly function to the tolerance of component,  $t_{ij}$  is tolerance of component  $i$  which supplied by supplier  $j$ ,  $Cp$  is process capability of assembly process.

### 3.2. Constraints

The constraints of the model in this paper consist of assembly tolerance, minimum number of supplier for each component, technology capability of suppliers, production capacity for each supplier, and assembly demand.

#### 3.2.1. Assembly quality

The assembly quality can be represented by its variance. The company sets the assembly tolerance which can be converted to variance by dividing the tolerance with the process capability index.

The tolerance is set by the company to maintain the quality of the product. The assembly variance is resulted from the accumulation of components variances that make up the assembly. The quality constraint is needed to ensure the resulted assembly variance does not exceed the maximum variance set by the company. Equation (7) expresses the constraint. The left hand side of the equation expresses the variances accumulation of all the needed components in the assembly of final product which must be multiplied by the binary variable of suppliers selection denoted by  $x_{ij}$ . The right hand side of the equation is the maximum variance that must be attained to maintain the assembly quality.

$$\sum_{i=1}^I \sum_{j=1}^J \left( \frac{\partial f(t)}{\partial t} \right)^2 \left( \frac{t_{ij}}{Cp_j} \right)^2 x_{ij} \leq \left( \frac{T_k}{Cp} \right)^2, \quad \forall k \quad (7)$$

### 3.2.2. Minimum number of selected suppliers

The company must determine the minimum number of selected suppliers to ensure all the needed components in assembly process can be provided by the suppliers. The constraint is expressed as in Equation (8). In this equation,  $N_i$  denotes the minimum number of suppliers for component  $i$ .

$$\sum_{j=1}^J x_{ij} \geq N_i, \quad \forall i \quad (8)$$

### 3.2.3. Technological capability

Each supplier has its own technological capability to manufacture certain types of components. In this paper, the suppliers have certain technological capabilities to manufacture certain types of components. This constraint is expressed in Equation (9). In this equation,  $O_j$  denotes the maximum technological capability which expresses in term of maximum number of component types that can be manufactured by a supplier.

$$\sum_{i=1}^I x_{ij} \leq O_j, \quad \forall j \quad (9)$$

### 3.2.4. Production capacity

The production capacity of each supplier must be considered in the model so the company will not allocate the components more than supplier's capacity. This constraint bounds the maximum quantity of each component which can be manufactured by each supplier. This constraint is expressed in Equation (10). In this equation,  $y_{ij}$  denotes the allocation of component  $i$  to supplier  $j$ , while  $C_{ij}$  denotes the maximum production capacity of supplier  $j$  in supplying component  $i$ .

$$y_{ij} \leq C_{ij}, \quad \forall i \text{ and } j \quad (10)$$

### 3.2.5. Assembly product demand

This constraint determines the total number of each component needed in assembly process. The expression of this constraint can be seen in Equation (11). In this equation,  $b_i$  and  $D$  denote the unit component  $i$  needed in a final assembly and final product demand respectively.

$$\sum_{j=1}^J x_{ij} y_{ij} = b_i D \quad (11)$$

## 4. Numerical example and analysis

In this numerical example, we use the assembly in Figure 1. The assembly consists of three components in which each component has one dimension. The dimension of  $x_1$ ,  $x_2$ , and  $x_3$  are 38, 42, and 80 mm respectively. The parameter data are obtained from Cao et al. (2009). Gap  $x_0$  is required to be 0.2 mm to maintain the normal performance. In this numerical example, we assume that there are three levels of quality (good, general, and poor). Each quality level has a different quality loss, as shown in Table 1.

Figure 1. Assembly for numerical example.

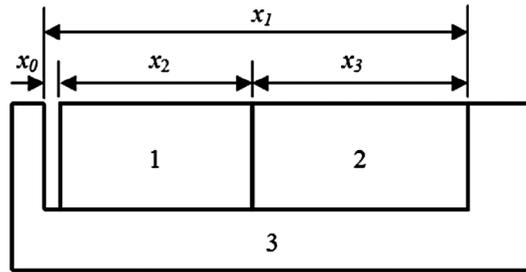


Table 1. Quality level and its loss

Quality level, $i$	Fuzzy quality sets, $\bar{A}$	Quality loss, $L$	Semantic quality
1	$\bar{A}_1$	$L_1 = 0$	Good quality
2	$\bar{A}_2$	$L_2 = 50,000$	General quality
3	$\bar{A}_3$	$L_3 = 65,000$	Poor quality

Each semantic quality in Table 1 is determined by a subject function. The subject function is defined based on engineering knowledge and experience (Hsieh, 2007). We use trapezium fuzzy sets for good and bad quality and triangle fuzzy set for general quality following research (Cao et al., 2009). The subject function of good quality assembly is shown in Equation (12):

$$\mu_{\bar{A}_1} = \begin{cases} 0, & y < 0.12 \\ (50y - 6)/3, & 0.12 \leq y < 0.18 \\ 1, & 0.18 \leq y < 0.22 \\ (14 - 50y)/3, & 0.22 \leq y < 0.28 \\ 0, & y > 0.28 \end{cases} \quad (12)$$

The subject function of quality characteristic  $y$  for quality level  $\mu_{\bar{A}_2}$  (general quality) is shown in Equation (13):

$$\mu_{\bar{A}_2} = \begin{cases} 0, & y < 0.08 \\ (25y - 2)/3, & 0.08 \leq y < 0.20 \\ (8 - 25y)/3, & 0.20 \leq y < 0.32 \\ 0, & y > 0.32 \end{cases} \quad (13)$$

The subject function for the poor quality grade is shown in Equation (14):

$$\mu_{\bar{A}_3} = \begin{cases} 1, & y < 0.08 \\ 1.8 - 10y, & 0.08 \leq y < 0.18 \\ 0, & 0.18 \leq y < 0.22 \\ 10y - 2.2, & 0.22 \leq y < 0.28 \\ 1, & y > 0.28 \end{cases} \quad (14)$$

Several parameters are used in the model. The first parameter is the tolerance component and its corresponding price. The tighter the tolerance, the higher the price of the component is, due to the use of more precise manufacturing facilities and tools in producing the component. The component tolerance and its corresponding price can be seen in Table 2. The data in the table are needed as input parameters for Equation (7) and to determine the purchasing cost in the objective function.

**Table 2. Component tolerance in its corresponding price**

Suppliers	Component C <sub>1</sub>		Component C <sub>2</sub>		Component C <sub>3</sub>	
	Tolerance (mm)	Price (IDR)	Tolerance (mm)	Price (IDR)	Tolerance (mm)	Price (IDR)
S <sub>1</sub>	0.07	17,000	0.07	20,000	0.07	25,000
S <sub>2</sub>	0.08	16,000	0.08	19,500	0.08	24,500
S <sub>3</sub>	0.09	15,000	0.09	18,000	0.09	20,000

**Table 3. Technological capability of the suppliers**

Suppliers	Technological capability
S <sub>1</sub>	3
S <sub>2</sub>	3
S <sub>3</sub>	3

The second parameter used in the model is the technological capability of the suppliers. In this paper, technological capability states the ability of the suppliers in producing the number of component types. For example, Suppliers 1 and 2 have three technological capability which means that the supplier can produce component C<sub>1</sub>, C<sub>2</sub>, and C<sub>3</sub> as shown in Table 3. The technological capability data in the Table are needed as the input data for Equation (9).

We also consider the production capacity and demand of the final product as input data for Equation (10). We assume that all suppliers have the same production capacities of 150 units for each components and the manufacturer received an order 150 units of demand of the final product. Each supplier is assumed to have the same process capabilities of 1. Since the final product needs one unit for each component, then the manufacturing company must order 150 units components from the suppliers. We also assume that the company has decided that there were minimum two suppliers must be selected for each component to ensure component's availability. This statement is needed as input data for Equation (8). The results of the optimization can be seen in Tables 4 and 5. In Table 4, we can see the component allocation of each component while the percentage of the final product in term of its fuzzy quality is shown in Table 5. The optimization resulted in IDR 8,692,000 of purchasing cost and IDR 4,204,617 of quality loss. Hence the total cost is IDR 13,166,811.

Sensitivity analysis is performed by change one of suppliers process capability index to determine how the index affecting the selected supplier and its allocation. We arbitrarily hange the process

**Table 4. Component allocation and selected suppliers**

Suppliers	Process capability index	Allocation			Cost	
		C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	Purchasing	Quality loss
S <sub>1</sub>	1.00	0	100	50	8,692,000	4,474,810
S <sub>2</sub>	1.00	50	28	0		
S <sub>3</sub>	1.00	100	22	100		
S <sub>1</sub>	1.00	0	50	50	8,350,000	4,204,617
S <sub>2</sub>	1.00	50	0	0		
S <sub>3</sub>	1.50	100	100	100		
S <sub>1</sub>	1.00	0	50	50	8,350,000	4,032,649
S <sub>2</sub>	1.00	50	0	0		
S <sub>3</sub>	2.00	100	100	100		

**Table 5. Percentage and fuzzy quality loss for each quality level**

Quality level	Percentage (%)	Fuzzy quality loss (IDR)
Good quality	43.94	0
General quality	44.05	3,303,720
Poor quality	12.01	1,171,090

capability index of Supplier 3. When the  $C_p$  of Supplier 3 is changed from 1 to 1.5, the allocation of Component 2 from this supplier increase from 22 to 100 units. This increase directly affect the allocation of Component 2 from the other suppliers. When  $C_p$  of Supplier 3 is changed to 2, the allocation is not affected by the increase of the  $C_p$ . The purchasing cost decreases from IDR 8,692,000 to 8,350,00. The decrease of this cost occurs when the  $C_p$  of Supplier 3 is changed from 1 to 1.5. This cost is not affected by the increase of the  $C_p$  from 1.5 to 2. The fuzzy quality loss decreases due to the increase of  $C_p$  of Supplier 3. This decrease is logical since the increase of  $C_p$  will gradually decrease the quality loss due to the smaller assembly variance. The resulted percentage of each quality level is shown in Table 5. The table shows that the percentage of the good quality increase due to the increase of  $C_p$ .

### 5. Conclusions

In this paper, an optimization model was developed to aid a decision-maker in selecting suppliers and allocating the components to the selected suppliers. Several constraints are considered in this paper such as assembly tolerance and technological and process capability of the suppliers in producing the components. Fuzzy quality loss was integrated in the model to measure the loss due to fuzziness of resulted assembly tolerance. In fuzzy quality loss, the assembly can be divided into several grades. From the sensitivity analysis, the increase of  $C_p$  in one of supplier affected the supplier selection and component allocation specially when the  $C_p$  increases from 1 to 1.5. The higher the  $C_p$  in one of the supplier the lower the percentage of poor quality and hence the lower the fuzzy quality loss. In future research the model can be extended by considering the complexity of product in modular structure to determine the performance of the model in coping with the larger and more complex problem. Another direction of future research can be directed to include the lotsizing decision and assembly scheduling in dynamic manufacturing environment.

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### References

Barthelemy, J. (2003). The seven deadly sins of outsourcing. *Academy Of Management Perspectives*, 7, 87–98.  
 Bayrak, M. Y., Çelebi, N., & Taşkin, H. (2007). A fuzzy approach method for supplier selection. *Production Planning & Control*, 18, 54–63.  
<http://dx.doi.org/10.1080/09537280600940713>

Cao, Y., Mao, J., Ching, H., & dan Yang, J. (2009). A robust tolerance optimization method based on fuzzy quality loss. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 223, 2647–2653.  
 Cao, Y., Mao, J., Yang, J., Wu, Z., & Wu, L. (2006). A robust tolerance design method based on fuzzy quality loss. *Frontiers of Mechanical Engineering in China*, 1, 101–105.  
<http://dx.doi.org/10.1007/s11465-005-0010-y>  
 Chase, K. W., Greenwood, W. H., Loosli, B. G., & Hauglund, L. F. (1990). Least cost tolerance allocation for mechanical assembly with automated process selection. *Manufacturing Review*, 3, 49–59.  
 Chen, F., Tzeng, Y., Hsu, M., & Chen, W. (2010). Combining taguchi method, principal component analysis and fuzzy logic to the tolerance design of a dual-purpose six bar mechanism. *Transactions of the Canadian Society for Mechanical Engineering*, 34, 277–293.  
 Feng, C. X., Wang, J., & dan Wang, J. S. (2000). An optimization model for concurrent selection of tolerances and supplier. *Computers & Industrial Engineering*, 40, 15–33.  
 Fors, H. N., Harraz, N. A., & Abouli, M. G. (2011). Supplier selection and order allocation in supply chain management. *Proceedings of the 41st International Conference on Computers & Industrial Engineering*, Los Angeles, CA.  
 Ghorbeni, M., Bahrami, M., & Arabzad, S. M. (2012). Integrated model for supplier selection and order allocation, using shannon entropy, SWOT, and linear programming. *Procedia Social and Behavioral Sciences*, 14, 521–527.

- Guneri, A. F., & Kuzu, A. (2009). Supplier selection by using a fuzzy approach in just-in-time: A case study. *International Journal of Computer Integrated Manufacturing*, 22, 774–783. <http://dx.doi.org/10.1080/09511920902741075>
- Hsieh, K. L. (2007). Applying fuzzy set approach into achieving quality improvement for qualitative quality response. *Proceedings of the 2007 WSEAS International Conference on Computer Engineering and Applications*, Gold Coast.
- Kahraman, C., Ertay, T., & Buyukozkan, G. (2006). A fuzzy optimization model for QFD planning process using analytic network approach. *European Journal of Operational Research*, 171, 390–411.
- Linn, R. J., Tsung, F., & Ellis, L. W. C. (2006). Supplier selection based on process capability and price analysis. *Quality Engineering*, 18, 123–129. <http://dx.doi.org/10.1080/08982110600567475>
- Montgomery, D. C. (2001). *Introduction to statistical quality control* (4th ed.). New York, NY: Wiley.
- Nukala, S., & Gupta, S. M. (2007). A fuzzy mathematical programming approach for supplier selection in a closed-loop supply chain network. *Proceedings of the 2007 POM Dallas Meeting, Texas*.
- Pi, W., & Low, C. (2006). Supplier evaluation and selection via Taguchi loss functions and an AHP. *The International Journal of Advanced Manufacturing Technology*, 27, 625–630. <http://dx.doi.org/10.1007/s00170-004-2227-z>
- Rajan, A. J., Ganesh, K., & Narayanan, K. V. (2010). Application of integer linear programming model for vendor selection in a two stage supply chain. *International Conference on Industrial Engineering and Operation Management*, Dhaka.
- Rosyidi, C. N., Jauhari, W. A., & Sabatini, N. (2013). Simultaneous component and tolerance allocation through suppliers' selection considering technological capability and production capacity to minimise purchasing cost and quality loss. *International Journal of Logistics Economics and Globalisation*, 5, 302–311. <http://dx.doi.org/10.1504/IJLEG.2013.059165>
- Sabatini, N., Jauhari, W. A., & Rosyidi, C. N. (2011). Supplier selection model based on tolerance allocation to minimize purchasing cost and quality loss. *Proceedings of International Seminar on Industrial Engineering and Service Science, IESS*, Solo.
- Sarode, A. K., Sunnapwar, V. K., & Khodke, P. M. (2008). A Literature Review for Identification of Performance Measures for Establishing a Framework for Performance Measurement in Supply Chains. *International Journal of Applied Management and Technology*, 6, 241–273.
- Sodenkamp, M. A., & Suhl, L. (2012). A multicriteria multilevel group decision method for supplier selection and order allocation. *International Journal of Strategic Decision Sciences*, 3, 81–105. <http://dx.doi.org/10.4018/IJSDS>
- Stella, H., & Alena, V. (2012). Application of fuzzy principles in evaluating quality of manufacturing process. *WSEAS Transactions on Power Systems*, 7, 50–59.
- Teeravaraprug, J. (2008). Outsourcing and vendor selection model based on taguchi loss function. *Songklanakarinn Journal of Science and Technology*, 30, 523–530.
- Youn, B. D. (2005). Integrated framework for design optimization under aleatory and/or epistemic uncertainties using adaptive-loop method. *Proceedings of DETC '05*, California.
- Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, 8, 338–353. [http://dx.doi.org/10.1016/S0019-9958\(65\)90241-X](http://dx.doi.org/10.1016/S0019-9958(65)90241-X)



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