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Supplier evaluation and order allocation using fuzzy analytical hierarchy process and augmented epsilon constraint methods

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Abstract. Environmental issues nowadays affect the way to run business. These issues push firms to have effective and efficient green supply chain management. One of critical aspect in green supply chain management is green supplier selection. Choosing suitable supplier is an important part in procurement activity. Almost 70% of the total production cost is derived from raw material purchasing cost. This research proposes two phase meta-model for supplier selection and order allocation that takes into consideration environmental criteria besides traditional criteria such as quality, cost and delivery. For the purpose, fuzzy set and analytical hierarchical process (AHP) were combined. AHP was used to allow uncertainties and vagueness due to human decision making and subjective criteria. For order allocation phase, multi-objective mathematical programming method (MOMP), the augmented ϵ -constraint (AUGMECON) method was used to find Pareto optimal solutions for multiple sourcing. These proposed methods were tested in one of tire manufacturing company in Indonesia. The results show that the methods gave a 0.16% of the total cost lower than the existing one as addition to fulfilling green criteria.

1. Introduction

Nowadays, enterprises realize that effective and efficient supply chain management practices can affect both direct and indirect profit [1]. It is because enterprise must focus on reducing operational cost and enlarging overall profit to keep competitive in this globalization era [2]. However, due to environmental awareness issues, enterprises have to consider environmental aspect in managing their operations and supply chains. This consideration is often called as green supply chain management [2]. Global competition push firms to have effective and efficient green supply chain management.

According to [2], green supply chain management is the management of funds, information and product flow along all supply chain stages to find the right balance between environmental and economic aspects. One of critical aspect in supply chain management is supplier selection [3]. Choosing suitable supplier is important responsibility for any organization in procurement activity [4]. It can help manufacturer to have better performance such as increasing customer satisfaction and



reducing purchasing cost because almost 70% of the total production cost is derived from raw material purchasing cost [5].

There are two types of supplier selection; i.e. single-sourcing and multiple-sourcing. In single-sourcing, a single supplier can fully satisfy all demand of a company and the company only needs to decide the selected supplier. On the other hand, in multiple-sourcing, a single supplier cannot satisfy all demand so that the order need to be splitted among other selected suppliers [2]. Multiple sourcing is more preferable than single sourcing due to its order flexibility [6].

According to [7], multiple sourcing can be divided into three phase: (1) supplier evaluation: establishing a supplier base, (2) supplier selection: choosing suppliers from the base and (3) quantity allocation: determining the quantity order for each selected supplier. Supplier selection involve multiple criteria both qualitative and quantitative criteria. SS are complicated because some criteria may conflict with the other i.e. price and quality. In the past, it just focused on traditional criteria such as quality, cost, delivery not environmental criteria.

Supplier selection method can be classified as: (1) Multi criteria decision making (MCDM) technique such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order Performance by Similarity to ideal solution (TOPSIS), decision making trial and evaluation laboratory (DEMATEL); (2) Mathematical programming technique such as linear programming (LP), non-linear programming (NLP), multi-objecive linear programming (MOLP), goal programming (GP) and AUGMECON; (3) Artificial intelligence technique such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Chaotic Bee Colony.

In some literature, researchers not only discuss about supplier selection method but also combine it with order allocation method. [4] integrated fuzzy TOPSIS that is simple for computational procedure, easy to represent human preference, allow an unlimited number of criteria and an explicit trade-off between the criteria with fuzzy multi-objecive linear programming (MOLP). [2] used fuzzy TOPSIS to rank potential suppliers based on traditional and green criteria and then use AHP to get importance weight to each criteria in a multi-period model. They separated preference weight calculation between green and traditional criteria to provide flexibility for top management whether they choose to giving more or less importance weight to green criteria towards traditional criteria. [7] built news vendor single period model for quantitative sustainable sourcing to select suppliers and determine optimal order quantities restricted by uncertain end product demand and salvage value. They considered multiple suppliers, capacity constraints, fixed charges and price in their research. [8] used fuzzy TOPSIS for supplier evaluation and then used multi-objecive integer programming with fuzzy objectives and fuzzy constraints to determine optimal order quantity for allocated supplier.

Assuming that an enterprise has already established supplier data base, this research will only focus on supplier selection and quantity allocation. For supplier selection, fuzzy set and analytical hierarchical process (AHP) are combined to get weight of criteria importance. For quantity allocation phase, AUGMECON model introduced by [9] was used. The contribution of this research is to propose new meta-model for supplier selection and order allocation by combining fuzzy AHP and AUGMECON method.

2. Research Methodology

2.1. Fuzzy AHP

Fuzzy AHP can deal with uncertainties and vagueness of human decision making. In principle, fuzzy AHP is the same as classical AHP. AHP use crisp value but fuzzy AHP use fuzzy value. There are three main steps in fuzzy AHP: (1) problem structuring, (2) evaluation of local priorities, and (3) computing the global priorities of alternatives to come to a decision [5].

In problem structuring, decision maker states the objective, defines the selection criteria and picks the alternative choices to be selected from. In evaluation of local priorities, fuzzy is applied for determining pair-wise comparisons and local priorities. In last steps, global priorities of each alternative are computed. Consistency Ratio must be computed and should be less than 0.1.

2.2. Multi-Objective Mathematical Programming (MOMP)

In MOMP, there are more than one objective functions and they are usually conflicted. So, there is no single optimal solution that can optimize all the objective functions. Decision maker look for the most preferred solution rather than optimal solution. Concept of optimality is replaced by Pareto optimality or efficiency. [9] defined Pareto optimal solutions as solutions that cannot be improved in one objective function without deteriorating their performance in the others objective functions. Decision maker look for the most preferred solution among the Pareto optimal solutions.

2.3. Augmented ϵ -constraint (AUGMECON)

AUGMECON is an extended ϵ -constraint method that was introduced by [9]. AUGMECON optimizes one objective function using the other objective function as a constraint as shown in Equation (1) where eps is an adequately small number (usually between 10^{-3} and 10^{-6}), s_p is slack or surplus variable, and r_p is range of i -th objective function.

$$\max(f_1(x) + eps \times (s_2/r_2 + s_3/r_3 + \dots + s_p/r_p)) \tag{1}$$

This research was conducted through three major steps shown in Figure 1. For suppliers selection phase, data processing is done by using fuzzy AHP method and its output is the weight of criteria importance. The weights are incorporated into the supplier's assessment to obtain the qualitative value of each supplier. Order history data and qualitative values are used as input to create a multi-objective linear programming model that consisting of objective, constraint, and decision variables. After that, the calculation of order allocation is done by using AUGMECON method with the help of GAMS (General Algebraic Modeling System) software.

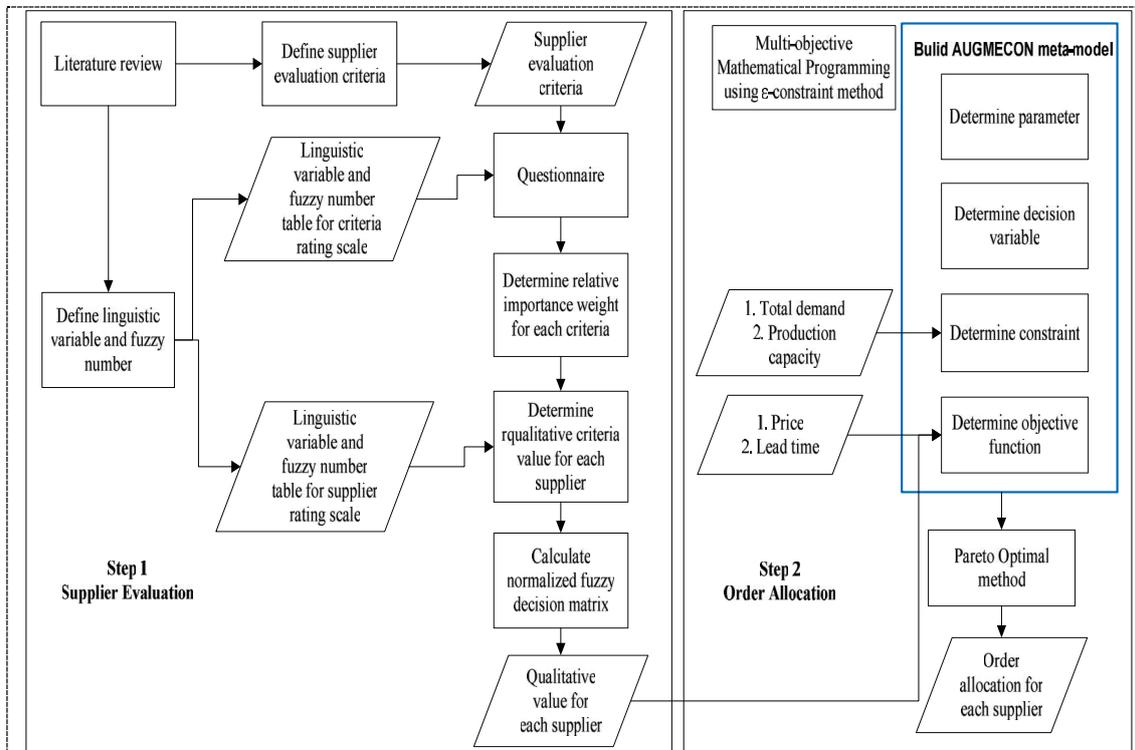


Figure 1. Research methodology.

3. Case Study

The proposed method was implemented in tire manufacture industry in Indonesia. Based on literature available, there are 41 sub-criteria for supplier selection that are grouped into 9 criteria: 8 traditional criteria and 1 green criteria. Full list of criteria and sub criteria are displayed on Table 1.

Table 1. Supplier selection criteria.

CRITERIA		SUB-CRITERIA	
A	Quality	A1	Rejected material ratio
		A2	Quality Management System/ ISO 9001 certification
		A3	Defect rate
		A4	Meeting minimum standard and requirement
B	Price/cost	B1	The average market price level of commodities
		B2	The lowest market price level of commodities
		B3	Shipping costs
		B4	Payment terms
		B5	Transaction price
		B6	Discount
C	Delivery	C1	Delivery time rate
		C2	Lead time delivery/geographical location
		C3	Delivery flexibility
		C4	Reserve capacity
		C5	Delivery quantity rate
		C6	Inventory availability
		C7	Order frequency
D	Service	D1	Quick response to customer demand
		D2	After sales support
		D3	E-transaction capability
E	Customer relations	E1	Willingness to share information
		E2	Long-term relationship development
F	Technical capability	F1	Continuous improvement ability
		F2	New product development ability
		F3	Technology sharing capability
		F4	Flexible production capability
G	Image	G1	Industry reputation
		G2	Past operation performance
H	Reliability	H1	Financial capability
		H2	Guarantee & liabilities / claim
		H3	Country's political situation
		H4	Currency exchange situation
I	Green competition / Environment Management Performance	I1	Environmental planning (program to reduce impacts, green research and development)
		I2	Selection of environmentally friendly materials (low waste: easy recycle and reuse capability)
		I3	Prohibited / toxic substances usage
		I4	Cleaner production technology (pollutant emission: CO2 equivalent, VOC, BOD and COD content and etc.)
		I5	Waste management
		I6	Environment Management System/ ISO 14001 certification
		I7	Green image
		I8	Green packaging
		I9	Distribution

Questionnaires were spread to make pair-wise comparison for each criteria in linguistic variable (represented in Table 2). The respondents for this research are manager, assistant manager and staff that are experienced in tire manufacturer procurement for several years. From 23 distributed questionnaires, only 9 questionnaires that were returned. To get preference weight for each criteria, pair-wise comparison matrix in fuzzy set was made (depicted in Table 3). Those 9 judgments were aggregated with geometric mean operation by using Equation (2) where l_{ij} , m_{ij} and u_{ij} are

respectively the lower, middle and upper values of the fuzzy membership function and K is number of decision maker.

$$l_{ij} = \left(\prod_{k=1}^K l_{ijk} \right)^{1/K}, m_{ij} = \left(\prod_{k=1}^K m_{ijk} \right)^{1/K}, u_{ij} = \left(\prod_{k=1}^K u_{ijk} \right)^{1/K} \tag{2}$$

Table 2. Linguistic variable for importance scale.

Linguistic variable	TFN ((l, m, u))
Very not important	(1, 1, 1)
Not important	(1, 3, 5)
Netral	(3, 5, 7)
Important	(5, 7, 9)
Very important	(7, 9, 9)

Table 3. Linguistic variable for evaluation of qualitative criteria values for pairwise comparison.

Linguistic variable	TFN ((l, m, u))	Reciprocal
Equally important	(1, 1, 1)	(1, 1, 1)
Moderately important	(1, 3, 5)	(1/5, 1/3, 1)
More important	(3, 5, 7)	(1/7, 1/5, 1/3)
Very important	(5, 7, 9)	(1/9, 1/7, 1/5)
Extremely important	(7, 9, 9)	(1/9, 1/9, 1/7)

Defuzzification was carried out to get a single digit of three fuzzy numbers. Center of Area (COA) is used to calculate the value of best non-fuzzy performance (BNP). If the BNP_i value is represented as the BNP value for criteria i , the BNP of the COA is calculated by Equation (3) as follows:

$$BNP_i = \frac{(l_i + m_i + u_i)}{3} \tag{3}$$

The next step is to calculate the criteria weight which is the standardization value of BNP_i ($STD - BNP_i$) shown as Equation (4) below:

$$Weight = STD - BNP_i = BNP_i / \sum_{i=1}^n BNP_i \tag{4}$$

Determining the fuzzy priority of qualitative criteria for supplier alternatives is using the linguistic variables shown in Table 4. The weights of each criteria and the value of fuzzy performance are integrated to obtain the fuzzy synthetic decision matrix. Ranking results of fuzzy synthetic decision matrix is given by defuzzification using Center of Gravity method.

Table 4. Linguistic variable for supplier evaluation.

Importance intensity	TFN ((l, m, u))
Very good	(3, 5, 5)
Good	(1, 3, 5)
Enough	(1, 1, 1)
Not good	(1/5, 1/3, 1)
Not very good	(1/5, 1/5, 1/3)

The weight of qualitative criteria of each supplier in Table 5 will be used as input coefficients of one objective function for multi-objective optimization formulation by using AUGMECON method at the allocation order phase.

Table 5. Weight of qualitative value weight for each supplier.

Supplier	Qualitative value weight
1	0.21664
2	0.249993
3	0.249993
4	0.283375

Decision variable:

x_i = order quantity of i-th supplier for $i = 1, 2, \dots, n$

Objective function:

There are three objective functions in determining order allocation i.e. minimizing total cost (f_1), minimizing mean delivery time (f_2) and maximizing qualitative value (f_3).

Function 1 (f_1) is obtained by multiplying the material price with order quantity then added with the shipping cost. Function 2 (f_2) is obtained by multiplying the delivery time with order quantity then divided by the total demand. Function 3 (f_3) is obtained by multiplying the weight of the qualitative value with order quantity.

Constraint:

Order quantity of each supplier should not exceed the maximum production capacity and must exceed the minimum order quantity. Total quantity of orders for all suppliers must equal with total demand. Total cost incurred should not be more than the multiplication of the average market price level of the commodity with total demand. Total cost incurred is more than equal to the multiplication of the lowest commodity market price level with total demand. All constraints are represented in Equations (8) - (12).

$$\min f_1(x) = \sum_{i=1}^n p_i x_i + \sum_{i=1}^n d_i \tag{5}$$

$$\min f_2(x) = \sum_{i=1}^n \frac{t_i x_i}{Q} \tag{6}$$

$$\max f_3(x) = \sum_{i=1}^n w_i x_i \tag{7}$$

St

$$x_i \geq M_i \tag{8}$$

$$x_i \leq C_i \tag{9}$$

$$\sum_{i=1}^n x_i = Q \tag{10}$$

$$f_1(x) \leq p_{AVE} \times Q \tag{11}$$

$$f_1(x) \geq p_{MIN} \times Q \tag{12}$$

where

n : number of supplier

w_i : qualitative value weight of i-th supplier that obtained from fuzzy AHP method in supplier evaluation

x_i : order quantity of i-th supplier

p_i : material price of i-th supplier

d_i : delivery cost of i-th supplier

t_i : delivery time of i-th supplier

M_i : minimum order quantity of i-th supplier

Q : total demand

C_i : maximum production capacity of i-th supplier

p_{AVE} : the average market price of commodities

p_{MIN} : the minimum market price of commodities

For case study, data on Table 6 from one of tire manufacturing company were used.

Table 6. Order data history.

Material : CCC	Supplier 1	Supplier 2	Supplier 3	Supplier 4
p_i (\$/ MT)	5250	5100	5150	5170
M_i (MT)	0	0	0	0
d_i (\$/ MT)	0	0	0	0
t_i (hari)	14	14	14	14
C_i (MT)	5000	10000	70000	15000

Total demand $Q = 29000$ MT

Average market price of commodities $p_{AVE} = \$5167.5$ /MT

Minimum market price of commodities $p_{MIN} = \$5100$ /MT

Decision variable:

x_i = order quantity for supplier i where $i = 1, 2, 3,$ and 4

Objective function:

Minimize total cost function:

$$\min f_1(x) = p_1x_1 + p_2x_2 + p_3x_3 + p_4x_4 + d_1 + d_2 + d_3 + d_4$$

$$\min f_1(x) = 5250 x_1 + 5100 x_2 + 5150 x_3 + 5170x_4$$

Minimize mean delivery time function:

$$\min f_2(x) = \frac{t_1x_1 + t_2x_2 + t_3x_3 + t_4x_4}{Q}$$

$$\min f_2(x) = \frac{14 x_1 + 14 x_2 + 14x_3 + 14 x_4}{29000}$$

Maximize qualitative value function:

$$\max f_3(x) = w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4$$

$$\max f_3(x) = 0.21664 x_1 + 0.249993 x_2 + 0.249993 x_3 + 0.283375 x_4$$

Constraint:

$$x_1, x_2, x_3, x_4 \geq 0$$

$$x_1 \leq 5000$$

$$x_2 \leq 10000$$

$$x_3 \leq 70000$$

$$x_4 \leq 15000$$

$$x_1 + x_2 + x_3 + x_4 = 29000$$

$$f_1(x) \leq 5167.5 \times 29000$$

$$f_1(x) \leq 149,857,500$$

$$f_1(x) \geq 5100 \times 29000$$

$$f_1(x) \geq 147,900,000$$

Calculation for order allocation model is solved by using GAMS (General Algebraic Modeling System) software.

4. Result and Discussion

Fuzzy priority estimation result for each supplier evaluation criteria were shown in Table 7. The table clearly shows that tire manufacturing industry in Indonesia are using only traditional criteria when selecting their suppliers while green competence/environmental management performance criteria are not yet used. This is evidenced by the position of quality criteria, price/cost and delivery that occupy the top three ranks. But, green competence/environmental management performance criteria has no weight value.

Table 7. Weight and ranking for supplier evaluation criteria.

Criteria	Weight	Ranking
Quality	0.923754	1
Price/cost	0.0642950	2
Delivery	0.011554	3
Service	0.0003770	4
Customer relations	0.000012	5
Technical capability	0.000008	6
Image	0	7
Reliability	0	8
Green competition/Environment Management Performance	0	9

Summary of consistency ratio (CR) for nine respondents is shown in Table 8. Table 8 indicates that all CR values are less than 0.1. The values mean that all the nine respondent ratios can be used for weighting the criteria.

Table 8. Consistency ratio for each respondent.

Respondent	Consistency Ratio
1	-0.676
2	-0.714
3	-0.680
4	-0.680
5	-0.743
6	-0.704
7	-0.647
8	-0.717
9	-0.652

For order allocation calculation, three experiments were conducted with variation of number of optimal Pareto solution to be produced (shown in Table 9). The optimal number of Pareto solutions can be set by determining the same number of intervals using the equidistant grid point in the program. Computation time is also recorded when GAMS software is run on a computer with a 3.5 GHz Quad-core processor with Microsoft Windows 10 OS.

Table 9. Trial summary

Trial	Number of equal interval	Total gridpoint	Number of total run	Number of optimal Pareto solutions	Computation time (second)
1	10	11	11 ³ = 1331	11	6.656
2	21	22	22 ³ = 10648	22	60.125
3	50	51	51 ³ = 132651	51	140.453

To get the most preferred optimal Pareto solution, decision maker are involved in the interactive filtering process. Interactive filtering uses the results of Pareto's third experimental optimization experiment and performed three times as shown in Figures 2, 3, and 4. f_1 , f_2 and f_3 are the minimizing total cost, minimizing mean delivery time, and maximizing qualitative value functions, respectively. Objective function results for first, second, and third run are summarized on Tables 10-12.

From the third filtering shown in Figure 4, the decision maker chose solution number 2551 as the most preferred efficient solution. It's because solution number 2251 has the greatest qualitative value compared to other solutions. The interactive filtering process is terminated until the third iteration. As the result, the order quantity variables for the chosen solution are $x_1 = 0$, $x_2 = 10,000$ MT, $x_3 = 4,000$ MT, and $x_4 = 15,000$ MT.

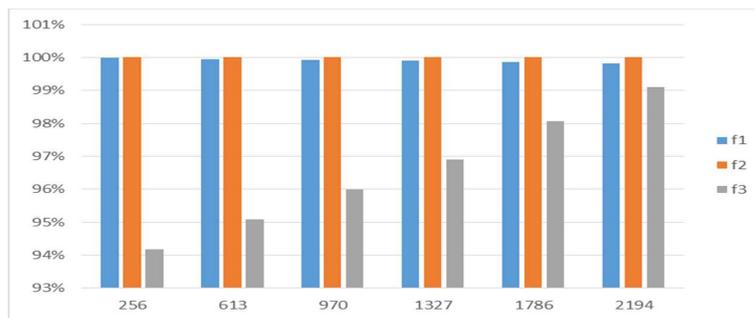


Figure 2. Subset of Pareto optimal solutions after order allocation first filtering.

Table 10. Objective function value and order quantity after order allocation first filtering

No	No. Solution	f_1	f_2	f_3	x_1	x_2	x_3	x_4
6	256	148880	406000	7299.87	0	10000	17500	1500
13	613	148922	406000	7369.97	0	10000	15400	3600
20	970	148964	406000	7440.07	0	10000	13300	5700
27	1327	149006	406000	7510.18	0	10000	11200	7800
36	1786	149060	406000	7600.31	0	10000	8500	10500
44	2194	149108	406000	7680.42	0	10000	6100	12900

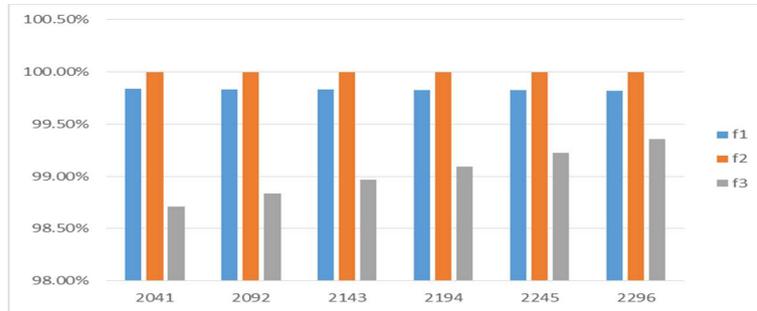


Figure 3. Subset of Pareto optimal solutions after order allocation second filtering.

Table 11. Objective function value and order quantity after order allocation second filtering

No	No. Solution	f_1	f_2	f_3	x_1	x_2	x_3	x_4
41	2041	148880	406000	7299.87	0	10000	7000	12000
42	2092	148922	406000	7369.97	0	10000	6700	12300
43	2143	148964	406000	7440.07	0	10000	6400	12600
44	2194	149006	406000	7510.18	0	10000	6100	12900
45	2245	149060	406000	7600.31	0	10000	5800	13200
46	2296	149108	406000	7680.42	0	10000	5500	13500

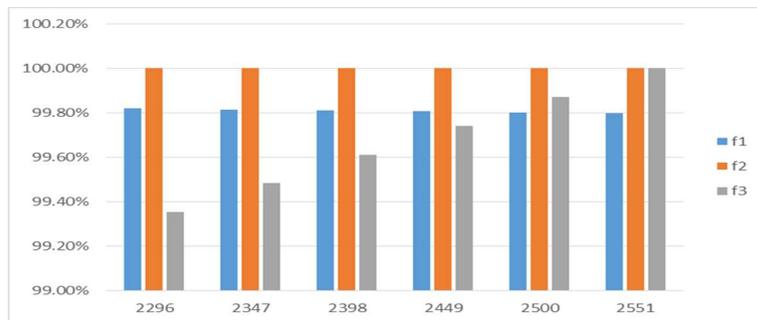


Figure 4. Subset of Pareto optimal solutions after order allocation third filtering.

Table 12. Objective function value and order quantity after order allocation third filtering.

No	No. Solution	f_1	f_2	f_3	x_1	x_2	x_3	x_4
46	2296	149120	406000	7700.45	0	10000	5500	13500
47	2347	149126	406000	7710.47	0	10000	5200	13800
48	2398	149132	406000	7720.48	0	10000	4900	14100
49	2449	149138	406000	7730.5	0	10000	4600	14400
50	2500	149144	406000	7740.51	0	10000	4300	14700
51	2551	149150	406000	7750.53	0	10000	4000	15000

Comparison of order allocation of selected solution from interactive filtering results with existing orders in terms of total cost is shown in Table 13. From these results, it appears that order allocation of the selected solution resulted \$240 cheaper than the existing order in terms of total cost. Selected solution gives 0.16% of the total cost lower than the existing order. Therefore, order allocation of selected solution proves to be more advantageous rather than the existing order in terms of total cost.

Table 13. Total cost comparison for selected solutions and existing order

	Material Price (\$/MT)	Selected solution(MT)	Existing order(MT)
x ₁	5250	0	2000
x ₂	5100	10000	8000
x ₃	5150	4000	7000
x ₄	5170	15000	12000
	Total cost (\$)	149150	149390

5. Conclusion

This study uses the combination of fuzzy AHP and AUGMECON methods to provide order allocation in multiple-sourcing cases involving subjective human decision making. In this study, GAMS (General Algebraic Modeling System) software is used to obtain the optimal solution set in multi-objective mathematical programming (MOMP) problems. To get the most preferred optimal solution, an interactive filtering method involves decision-making preferences. As a result, the order quantity variables for the chosen solution are $x_1 = 0$, $x_2 = 10,000$ MT, $x_3 = 4,000$ MT, and $x_4 = 15,000$ MT. The selected solution gives 0.16% of the total cost lower than the existing order.

The advantages of this model are to provide an order allocation solution in real time and involve the decision maker's preference for selection of solutions. While the weakness is this model is only applicable to the problem of allocation of orders for one type of multi-product suppliers. However, this model can be easily developed by the mathematical model for multi-product order allocation order issues in subsequent research. In terms of novelty, this model can complete the calculation of the allocation of orders quickly and simply. The proposed model can be applied to all industrial areas because the supplier evaluation criteria used are general.

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