Jurnal Teknik Industri, Vol. 27, No. 1, June 2025 DOI: https://doi.org/10.9744/jti.27.1.137-150
ISSN 1411-2485 print / ISSN 2087-7439 online

Supplier Selection and Order Allocation in A Pharmaceutical Wholesaler

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Abstract: Supplier selection is essential for any organization , as it plays a significant role in enhancing productivity. This study focuses on a local pharmaceutical wholesaler (PW) company, which places orders with other local PWs to meet its demand. Typically, pharmaceutical companies rely on multiple suppliers to satisfy their needs. However, due to an inadequate evaluation of supplier criteria, a Multi-Criteria Decision Making (MCDM) approach has been implemented to assist the PW in selecting superior suppliers and ensuring an efficient selection process. A key issue in this case study is the lack of a structured method for assessing supplier criteria, resulting in a subjective and lengthy selection process. The criteria for supplier selection encompass quality, flexibility, price, delivery, service, and supplier profile. Furthermore, alongside supplier selection, optimizing order allocation is essential for reducing purchasing costs while maximizing supplier scores. This research proposes a model designed to aid PW in addressing both supplier selection and order allocation challenges. The MCDM framework commences with the Best Worst Method (BWM) to establish the weight of each criterion. These weights then serve as input for the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), which ranks and prioritizes suppliers based on their evaluation scores. Subsequently, the results from TOPSIS inform the determination of optimal order allocation through a Multi-Objective Optimization (MOO) method. As part of the system modeling, a sensitivity analysis was performed to explore the effects of specific parameters on the objective function and decision variables, assessing variations in inventory costs, shortage costs, and demand. The findings indicated that only the demand parameter had a significant effect on decision variables, particularly regarding inventory levels and shortages. This research offers a comprehensive solution for the PW to tackle supplier selection and optimal order allocation. By employing MCDM and multi-objective optimization strategies, the company can achieve lower purchasing costs while selecting optimal suppliers based on their evaluation scores. The optimization model presented has dual objective functions: minimizing costs and maximizing total supplier value. Consequently, the model achieved a total purchasing cost of Rp. 340,196,740 and a total supplier value of 5,265,032.

Keywords: Supplier Selection, Order Allocation, BWM, TOPSIS, MOO.

Introduction

Supplier selection is the process by which buyers identify, evaluate, and contract with suppliers. It is one of the key success factors for a company; effective supplier selection can improve the overall quality of the company. Supplier selection is an important decision-making issue, as it can help reduce costs and enhance the company's competitiveness [1]. The difficulty in selecting suppliers for the PW lies in the absence of a clear assessment of criteria and suppliers, making the evaluation process subjective and time-consuming. An improper supplier selection process can lead to delays in the delivery of goods and product stockouts, resulting in losses for the company. Another issue concerns the fulfilment of order capacity, which must consider both the price and quality of the products delivered. Therefore, the selection process must be carried out accurately to ensure the right suppliers are chosen. To support effective supplier selection based on several predetermined criteria, a Multi-Criteria Decision Making (MCDM) approach can be used.

MCDM is a decision-making method used to determine the best alternative from several options by considering multiple criteria [2]. Criteria are typically measures, rules, or standards used in decision-making. In this research, the methods used are the Best Worst Method (BWM) and TOPSIS. BWM is one of the methods within MCDM, used to determine the weight of each criterion based on pairwise comparisons between the best and worst criteria and the other criteria [3]. Meanwhile, TOPSIS is a method that simultaneously considers the distance to the positive ideal solution and the distance to the negative ideal solution. The optimal solution in the TOPSIS method is obtained by determining the relative closeness of each alternative to the positive ideal solution. TOPSIS ranks the alternatives based on the priority of their relative closeness values. The ranked alternatives are then used as a reference by decision-makers to determine the best option.

In addition to supplier selection, another crucial decision that follows is order allocation [4]. To determine the optimal order allocation, an optimization model can be developed. In this research, a Multi-Objective Optimization model is proposed to address the order allocation problem. The objective functions of the model are to minimize the total purchasing cost and to maximize the total value of purchasing. The cost components considered in the model include order cost, shortage cost, and inventory cost. Additionally, the model accounts for product discounts and product shortages. This research contributes to the existing literature by incorporating discount levels for each purchase and by including the amount of shortage and inventory for each product in each period, adjusted to reflect real conditions in the pharmaceutical wholesaler case study.

Methods

Literature Review

Supplier selection is an important decision in supply chain management. In general, incorporating resilience strategies into supply chain management is essential for mitigating risks and disruptions that can impact business operations[5]. Therefore, companies must pay close attention to the supplier selection process to avoid mistakes that could lead to unnecessary costs. Supplier selection requires effort in identifying and evaluating suppliers based on a set of criteria. Although supplier selection may appear to be a simple task, it is actually one of the most critical stages in the supply chain. Choosing the wrong supplier can result in poor quality materials or extended delivery times, which may lead to customer dissatisfaction and both tangible and intangible losses for the company [6]. Supplier selection is very crucial step in supply chain management, it is a multicriteria decision-making problem that involves factors like quality, time, and cost [7]. Due to its complexity, robust methods and techniques are needed by companies in supplier selection. Many studies have suggested the application of several MCDM techniques to solve the supplier selection problem.

MCDM is a term for all methods or techniques that help people make decisions according to their preferences in situations where they face decision-making problems with conflicting criteria. [8]. Technically, MCDM is a method used in decision-making systems by comparing the weight assessments between criteria. There are three main steps in MCDM: identifying and selecting the criteria, determining the weight of the resources, and ranking the resources using a suitable MCDM method [2]. One of the main purposes of MCDM is to select the best alternative among the existing options or to determine the ranking of alternatives based on the weights assigned to each criterion.

The Best Worst Method (BWM) is a Multi-Criteria Decision-Making (MCDM) technique used to determine the weights of different criteria. BWM employs two pairwise comparison vectors to establish these weights: the best-to-others vector and the others-to-worst vector [3]. It is often considered superior to the Analytic Hierarchy Process (AHP) because it requires fewer comparisons. Additionally, the weight obtained from BWM is highly reliable and generally more consistent than those derived from AHP. The BWM process consists of five steps [3]: (1) Set criteria and sub-criteria. (2) Identity the best and the worst criteria. (3) Determine the preference for the best overall criterion. (4) Evaluate the preference of all criteria relative to the worst criterion. (6). Calculate the weight of each criterion. Saaty's scale can be used for the comparisons, as shown in Table 1.

Table 1. Saaty's scale

Numerical Value	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Demonstrated Importance
9	Absolute Importance
2,4,6,8	Intermediate Values

TOPSIS is a decision-making method under the multi-criteria decision-making (MCDM) framework that assesses alternatives based on their closeness to the best possible solution (Positive Ideal Solution or PIS) and their remoteness from the least favorable option (Negative Ideal Solution or NIS). This method is especially useful for identifying the most appropriate choice when dealing with numerous and potentially conflicting evaluation criteria [9]. Ranking in TOPSIS is calculated based on the relative closeness to the positive ideal solution. There are five steps in TOPSIS [10]: (1) Calculate the normalized decision matrix. (2) Calculate the weighted normalized decision matrix. (3) Determine the positive ideal solution (A^+) and negative ideal solution (A^-). (4) Calculate the distance of each alternative from the positive and negative ideal solutions. (5) Calculate the relative closeness coefficient of each alternative.

Order allocation is also an important decision in a company following supplier selection. However, determining the optimal order quantity is not an easy task, as order allocation involves multiple objectives [11], The main problem of order allocation is determining the optimal order for each supplier to minimize costs and other important objectives. An optimization model is needed to solve the order allocation problem A mathematical model can support decision-makers in the order allocation process by determining the optimal order quantity for each period, thus reducing the risk of potential losses. With mathematical modeling, the optimal solution can be found by maximizing or minimizing one or more objective functions subject to a set of constraints.

Research by [12] The supplier selection problem was solved in a plastic company in Indonesia. In the study, the supplier selection problem was addressed using the BWM and TOPSIS methods. There are four criteria and ten sub-criteria used in the research, namely price, delivery, order accuracy, and capability. The research involved 11 products and nine suppliers. The BWM method was used to determine the weight of each criterion, while TOPSIS was employed to calculate the final score of each supplier, which would then be used by the decision maker (DM) to rank the suppliers for each product.

Another research conducted by [13] To solve the supplier selection problem at Ridho Farma, a pharmacy company, the Simple Additive Weighting method was used. Five criteria were considered in the research: quality, delivery, price, trust, and responsiveness. The supplier selection and order allocation problems in the food industry were also discussed in [14]. The research considered multiple items, multiple periods, and quantity discounts. Two types of quantity discounts were considered: unit discount and incremental discount. TOPSIS was used to solve the supplier selection problem and obtain the ranking for each supplier for each product. Goal programming was used to solve the order allocation problem, with two objective functions: minimizing the total purchasing costs and maximizing the total purchasing value.

Based on previous research, this study aims to solve the supplier selection and order allocation problems in a PW company. BWM and TOPSIS are used to address the supplier selection problem, while the order allocation problem will be solved using Multi-Objective Optimization. Based on the literature review and the opinions of decision makers (DMs), 15 criteria are considered in this research. The optimization model in this research refers to [15]. However, the quantity discount system considered in this research is limited to the all-unit discount, as it is adjusted to the actual conditions of the PW company. The optimization model involves two objective functions: minimizing the total purchasing cost and maximizing the total purchasing value. These objective functions will then be combined using a transformation function. A comparison of this research with previous studies is shown in Table 2.

Table 2. Related research on supplier selection and order allocation

No.	Authors	Year	Characteristic				Solution Approach
			Supplier Selection	Order Allocation	Shortage	Level Discount	
1.	Sulistyoningrum, R & Rosyidi, C.N [12]	2019	√	-	-	-	BWM & TOPSIS
2.	Zulkarnain [13]	2023	√	-	-	-	SAW
3.	Nourmuhammadi [15]	2017	√	√	√	√	TOPSIS & Goal Programming
4.	This Research	2024	√	√	√	√	BWM, TOPSIS, MOO

System Description

Drugs are essential for supporting human health and enabling individuals to carry out their daily activities productively. Therefore, the criteria of effectiveness, safety, and quality must be considered in drug production. These criteria must be met throughout the entire process, from production and storage to distribution and delivery to consumers. This must be considered to ensure that the quality of the drug is maintained and that it is safe for patient consumption. The pharmaceutical industry typically relies on companies known as Pharmaceutical Wholesalers (PWs) for drug distribution. To achieve the goal of equitable access to medicines, the distribution of pharmaceutical preparations is crucial. A PW is a legal entity authorized to procure, store, and distribute drugs or other medical materials in large quantities [14]. Therefore, PWs must be able to maintain the quality of drug distribution to ensure that pharmaceutical products are delivered safely and effectively. In other words, PWs are trusted companies responsible for distributing drugs of good quality. In their distribution, PWs are tasked with delivering drugs to locations such as drug stores, pharmacies, hospitals, and other local PWs or health service units designated by the Minister of Health. Therefore, supplier selection in PWs is crucial to avoid stockouts.

This research was conducted in a PW company. Currently, the supplier selection and order allocation are performed manually by the company, making the process time-consuming. The system under consideration is depicted in Figure 1.

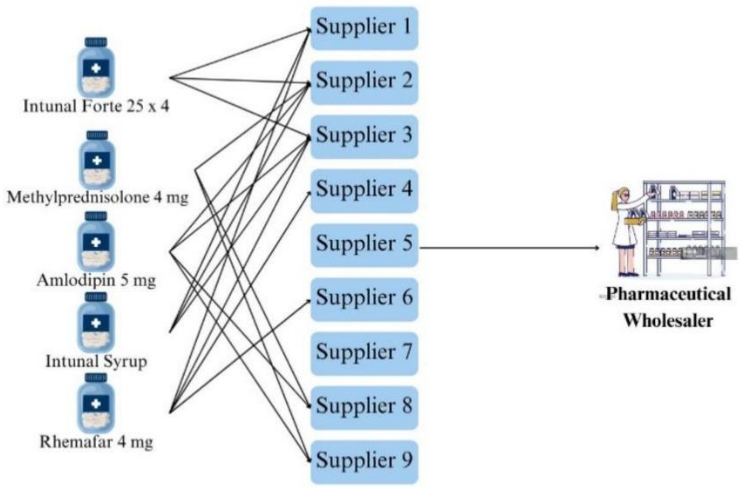

Figure 1. Drug distribution system

The drug distribution system in Indonesia begins with national PWs, which purchase drug products from drug manufacturers. The national PWs serve local PWs in fulfilling drug demand based on purchasing contracts. When local PWs experience a shortage of certain drugs, they typically place orders with other local PWs. The local PWs in need of drugs can purchase them from several other local PWs, which offer the drugs at discounted prices. In this research, we address the local PWs' problems in two stages. In the first stage, supplier selection is performed using BWM and TOPSIS to determine the weight of the criteria and supplier rankings, respectively. In the second stage, an optimization model is developed to solve the order allocation problem based on MOO.

In this research, supplier selection criteria were collected from previous studies. The criteria selected based on the literature review were then submitted to the Decision Makers (DMs) for validation. The validated criteria and sub-criteria used in this research are shown in Table 3.

There are two main topics in this study: supplier selection and order allocation. The price criterion is used in the supplier selection stage because price is one of the factors considered by the company to determine the most effective supplier. The weight of each criterion obtained in the supplier selection stage will be taken into account when determining the order quantity in the order allocation stage, in order to minimize total costs and maximize the total value of the supplier.

Table 3. Criteria and subcriteria based on study literature

Criteria	Sub-criteria	References
Quality	Product Specifications	[16]
	The Number of Defective Items	[16] and [17]
	Packaging and Labelling	[16] and [17]
Flexibility	Mode of payments accepted by the supplier	[18]
	Change of order quantity	[19] and [18]
	Change of order type of drug	[18]
	Due date for payments	[18]
Price	Unit Price	[17]
	Discount Price	[17]
Delivery	On time delivery	[16] and [18]
	Lead time	[18] and [17]
Service	After Sales Service (Warranty)	[18], [16], and [17]
	Ease of Communication	[17]
Supplier profile	Reputation of Supplier	[17]
	Past performance	[17]

The main assumptions of the problem are presented as follows: (1) Each criterion used in supplier selection is independent. (2) The weight of each decision-maker is equal. (3) The listed price includes shipping costs. (4) Storage costs are 2% of the purchase price. (5) Shortage costs are 20% of the purchase price. (6) The maximum shortage limit is 20% of the demand. (7) The discount level in the next period is assumed to be the same as in period 1.

Results and Discussions

Section 1. Best Worst Method.

In BWM, we first determine the best and worst criteria according to each DM. Afterwards, the DMs are asked to provide the weights for the comparison between Best to Others and Others to Worst. The comparison matrices are shown in Tables 4 and 5. For example, Table 4 shows that DM 1 considered Price as the best criterion, three times as important as Quality.

Table 4. Best-to-others matrix main criteria

DM	Best	Quality	Flexibility	Price	Delivery	Service	Supplier Profile
1	Price	3	5	1	5	6	8
2	Price	3	4	1	5	7	9

Table 5. Others-to-worst main criteria

DM	1	2
Worst	Supplier profile	Supplier profile
Quality	6	7
Flexibility	5	5
Price	8	9
Delivery	3	4
Service	3	3
Supplier Profile	1	1

Table 6. Main criteria weights

Main Criteria	DM		Average
	1	2	
Quality	0.186	0.183	0.185
Flexibility	0.112	0.137	0.125
Price	0.453	0.453	0.453
Delivery	0.112	0.109	0.011
Service	0.093	0.078	0.086
Supplier Profile	0.043	0.039	0.041
CR	0.023	0.018	0.020

After interviewing decision-makers (DMs) about the weights of each criterion in the Best-to-Others and Others-to-Worst pairwise comparison matrices, we established the final weights for each criterion and calculated the consistency ratio (CR) value. Table 6 illustrates the main criteria weights as determined by the DMs, along with the resulting CR value. Once we confirmed that the CR value for both the main criteria and sub-criteria was consistent, we proceeded to determine the local and global weights for each sub-criterion. The global weight is calculated by multiplying the local weight of each sub-criterion by the corresponding criterion weight. The results of the Best-Worst Method (BWM) can be found in Table 7.

Table 7. Global weight of criteria

Criteria	Weight	Subcriteria	Local weight	Global weight
Quality	0.185	Product Specifications	0.655	0.121
		The Number of Defective Items	0.113	0.021
		Packaging and Labelling	0.233	0.043
Flexibility	0.125	Mode of payments accepted by the supplier	0.062	0.007
		Change of order quantity	0.217	0.027
		Change of order type of drug	0.358	0.044
		Due date for payments	0.364	0.045
Price	0.453	Unit Price	0.113	0.050
		Discount Price	0.888	0.402
Delivery	0.111	On time delivery	0.888	0.098
		Lead time	0.113	0.012
Service	0.086	After Sales Service (Warranty)	0.854	0.073
		Ease of Communication	0.146	0.012
Supplier Profile	0.041	Reputation of Supplier	0.188	0.007
		Past performance	0.813	0.033

There are two main topics in this study: Supplier selection and order allocation. The price criterion is used in the supplier selection stage because price is one of the factors considered by the company to determine which supplier is the most effective. The weight of each criterion obtained in the supplier selection stage will be taken into account when determining the order quantity in the order allocation stage, in order to minimize total purchasing costs and maximize the total value of the supplier.

Section 2. TOPSIS

The weights that have been obtained will be used as the input for the TOPSIS method, to determine the supplier priorities based on the scores by the following steps.

Define the decision matrix.

$$D = \begin{pmatrix} x_{11} & x_{12} \\ x_{21} & x_{22} \\ x_{31} & x_{23} \end{pmatrix} \quad (1)$$

Determine the normalized decision matrix.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (2)$$

Construct the weighted normalized decision matrix.

$$v_{ij} = w_i \times r_{ij} \quad (3)$$

Determine Positive Ideal Solution and Negative Ideal Solution.

$$(A^+) = \{(\max v_{ij} | j \in j), i = 1,2,3, \dots, m\} \quad (4)$$
$$(A^-) = \{(\min v_{ij} | j \in j), i = 1,2,3, \dots, m\}$$

Calculate the Distance from the Positive Ideal Solution and the Negative Ideal Solution.

$$S_i^{\ +} = \sqrt{\sum_{j=1}^{n} (v_j^{\ +} - v_{ij})^2} \qquad S_i^{\ -} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{\ -})^2} \quad (5)$$

Calculate the Relative Closeness to Positive Ideal Solution

$$C_i^+ = \frac{S_i^-}{S_i^- + S_i^+} \quad (6)$$

Equation (1) defines the decision matrix for each supplier and each criterion based on the DMs' preferences. Equation (2) normalizes the decision matrix by dividing the values in the decision matrix by the square root of the sum of the squared values. Equation (3) constructs the weighted normalized decision matrix by multiplying the normalized decision matrix values by the weight of each criterion. Equation (4) determines the positive and negative ideal solutions for each criterion. When the criterion is a benefit criterion, the positive ideal solution is obtained by selecting the maximum value in the weighted normalized decision matrix, while the negative ideal solution is obtained by selecting the minimum value in the weighted normalized decision matrix. When the criterion is a cost criterion, the positive ideal solution is obtained by selecting the minimum value in the weighted normalized decision matrix, while the negative ideal solution is obtained by selecting the maximum value in the weighted normalized decision matrix. Equation (5) calculates the distance from both the positive ideal solution and the negative ideal solution. The distance of an alternative to the positive ideal solution is calculated by taking the square root of the sum of the squared differences between the values in the weighted normalized decision matrix and the positive ideal solution, while the distance of an alternative to the negative ideal solution is calculated by taking the square root of the sum of the squared differences between the values in the weighted normalized decision matrix and the negative ideal solution. Equation (6) calculates the relative closeness to the positive ideal solution by dividing the distance to the negative ideal solution by the sum of the distances to both the negative and positive ideal solutions.

After the six steps of the TOPSIS method are completed, the score for each drug from each supplier is determined, as shown in Table 8. Based on this table, the final ranking of each supplier for each drug is determined, as shown in Table 9.

Table 8. Score for each drug from each supplier

Drug	Supplier								
	S1	S2	S3	S4	S5	S6	S7	S8	S9
Intunal Forte 25x4	0.382	0.622	0.499						
Methylprednisolone 4 mg		0.727						0.386	0.278
Amlodipin 5 mg		0.725	0.643					0.324	0.275
Intunal Syrup	0.382	0.618	0.498						
Rhemafar 4 mg	0.428		0.575	0.322		0.287			

Table 9. TOPSIS calculation ranking each item

Drug	Supplier								
	S1	S2	S3	S4	S5	S6	S7	S8	S9
Intunal Forte 25x4	3	1	2						
Methylprednisolone 4 mg		1						2	3
Amlodipin 5 mg		1	2					3	4
Intunal Syrup	3	1	2						
Rhemafar 4 mg	2		1	3		4			

After TOPSIS is completed, the final score of each supplier will be used as the input in the second stage of the research to determine optimal order allocation.

Section 3. Multi Objective Optimization

Model Formulation

The optimization model used in this research is based on the research of [15]. The model formulation is described as follows:

Indices:

i : Index for Drug ($i = 1,2, \dots, I$)

j : Index for Supplier ($j = 1,2, \dots, J$)

t : Index for Period ($t = 1,2, \dots, T$)

k : Index of Discount Ranges ($k = 1,2, \dots, K$)

Parameters:

P_{ijk} : The price of drug i from supplier j in discount range k (IDR/pc).
D_{it} : Demand of drug i at periode t (pcs).
H_{it} : Holding Cost of drug i at periode t (IDR/pc)
BC_i : Shortage Cost of drug i (IDR/pc)
W_{ij} : Score of drug i from supplier j.
C_{ij} : Capacity of drug i at Supplier j (pcs).
S_i : Maximum inventory of drug i (pcs).
L_{Max} : Maximum shortage allowed for each drug
U_{ijk} : Upper bound of the quantity of drug i of supplier j at discount range k .
L_{ijk} : Lower bound of the quantity of drug i of supplier j at discount range k
M : Big number (M = 1,000,000)
D'_{ij} : 1 if drug i is supplied by supplier j; 0 otherwise

Decision Variables:

X_{ijt} : Number of drug i bought from supplier j in period t (pcs).
Inv_{it} : Inventory level of drug i in period t (pcs).
B_{it} : Shortage quantity of drug i in period t (pcs).
Y_{jt} : 1 if an order is allocated to supplier j in period t; 0 otherwise
Y'_{ijk} : 1 if drug i is supplied by supplier j at discount range k; 0 otherwise.

The optimization model to solve the problems in this research are shown in Equation (1)-(13).

Objective Functions:

1. $$\text{Min } Z_1 = \frac{(\sum_i \sum_j \sum_t \sum_k (X_{ijt} \times P_{ijk} \times Y'_{ijk}) D'_{ij} + \sum_i \sum_t H_{it} \times Inv_{it} + \sum_i \sum_t BC_i \times B_{it}) - F_1^0}{F_1^{Max} - F_1^0} + \frac{F_2^0 - \sum_i \sum_j \sum_t X_{ijt} \times W_{ij}}{F_2^0 - F_2^{Min}} \quad \forall i,j,t,k \quad (7)$$

Constraints:

$$X_{ijt} \le C_{ij} \quad \forall i,j,t \quad (8)$$
$$X_{ijt} \le M \times Y_{jt} \quad \forall i,j,t \quad (9)$$
$$Inv_{it} \le S_i \quad \forall i,t \quad (10)$$
$$\frac{\sum_i \sum_t B_{it}}{\sum_i \sum_t D_{it}} \le L_{Max} \quad \forall i,t \quad (11)$$
$$\sum_j X_{ijt} - Inv_{it} + B_{it} = D_{it} \quad \forall i, t = 1 \quad (12)$$
$$\sum_j X_{ijt} + Inv_{i(t-1)} - Inv_{it} + B_{it} = D_{it} \quad \forall i, t > 1 \quad (13)$$
$$\sum_t X_{ijt} \le U_{ijk} + M(1 - Y'_{ijk} \times D'_{ij}) \quad \forall i,j,t,k \quad (14)$$
$$\sum_t X_{ijt} > L_{ijk} - M(1 - Y'_{ijk} \times D'_{ij}) \quad \forall i,j,t,k \quad (15)$$
$$\sum_k Y'_{ijk} = D'_{ij} \quad \forall i,j,k \quad (16)$$
$$X_{ijt}, B_{it}, Inv_{it} \ge 0 \quad \forall i,j,t,k \quad (17)$$
$$Y_{jt}, Y'_{ijk} \in \{0,1\} \quad \forall i,j,t,k \quad (18)$$

Equation (7) represents the objective functions of the model, namely minimizing the purchasing cost and maximizing the total value of purchasing. Equation (8) ensures that the number of drugs $\boldsymbol{i}$ ordered from supplier j in period t does not exceed the supplier's capacity. Equation (9) ensures that if a supplier is selected, it will receive the order allocation for the drug. Equation (10) limits the number of drugs in the inventory to its capacity. Equation (11) limits the maximum shortage. Equations (12) and (13) represent the inventory balance. Equations (14), (15), and (16) are used to match the discount price with the number of drugs purchased and to ensure consistency between the selected supplier and the allocation decision. Equations (17) and (18) define the non-negativity of the continuous decision variables and the binary decision variables, respectively.

In this research, we limit the study to five drugs from nine suppliers: Intunal Forte 25x4, Methylprednisolone 4 mg, Amlodipine 5 mg, Intunal syrup, and Rhemafar 4 mg. Tables 10-14 show the demand for each drug, the price and capacity of each supplier, the discount and its respective minimum order quantity for each product from each supplier, the maximum inventory for each drug, and the maximum shortage for each drug.

Table 10. Demand for each product and each period

Drug	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Intunal Forte 25x4	232	98	97	216	248	217	144	169	116	75	88	134
Methylprednisolone 4 mg	170	123	201	139	276	105	200	124	195	209	97	234
Amplodipin 5 mg	104	78	123	121	205	120	213	192	179	196	97	423
Intunal syrup	105	98	86	176	289	139	110	235	265	149	86	111
Rhemafar 4 mg	104	81	143	117	78	108	108	127	118	97	78	128

Table 11. Price and capacity for each product

Drug	Price (Rp)	Holding cost (Rp)	Shortage cost (Rp)	Supplier capacity (pcs/period)
Intunal Forte 25x4	89,910	1,798	17,982	80
Methylprednisolone 4 mg	44,456	889	8,891	80
Amplodipin 5 mg	96,872	1,937	19,374	100
Intunal syrup	22,200	444	4,440	90
Rhemafar 4 mg	58,806	1,172	11,722	85

Table 12. Discounts for each product from each supplier.

Drug	Supplier	Discount level		Minimum order quantity (Pcs)	
		Level 1	Level 2	Level 1	Level 2
Intunal Forte 25x4	Supplier 1	30%	30%	40	120
	Supplier 2	30%	32%		
	Supplier 3	30%	32%		
Methylprednisolone 4 mg	Supplier 2	64.5%	64.5%	70	210
	Supplier 8	64.5%	65%		
	Supplier 9	64.5%	64.5%		
Amplodipin 5 mg	Supplier 2	83.5%	83.5%	70	210
	Supplier 3	81%	81%		
	Supplier 8	81%	83.5%		
	Supplier 9	80%	80%		
Intunal Syrup	Supplier 1	27.5%	30%	50	150
	Supplier 2	30%	32%		
	Supplier 3	30%	32%		
Rhemafar 4 mg	Supplier 1	35%	35%	80	160
	Supplier 3	35%	35%		
	Supplier 4	35%	38%		
	Supplier 6	35%	35%		

Table 13. Maximum inventory for each drug

Drug	Maximum inventory (Pcs)
Intunal Forte 25x4	120
Methylprednisolone 4 mg	96
Amplodipin 5 mg	110
Intunal Syrup	156
Rhemafar 4 mg	44

Table 14. Maximum shortage for each drug for each period

Drug	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Intunal Forte 25x4	47	20	20	44	50	44	29	34	24	15	18	27
Methylprednisolone 4 mg	34	25	41	28	56	21	40	25	39	42	20	47
Amplodipin 5 mg	21	16	25	25	41	24	43	39	36	40	20	85
Intunal syrup	21	20	18	36	58	28	22	47	53	30	18	23
Rhemafar 4 mg	21	17	29	24	16	22	22	26	24	20	16	26

After determining the minimum and maximum values of each objective function, the two objective functions are combined into a single objective function based on the transformation function, as explained in [20]. The transformation function is shown in Equation (19) which will be used as the objective function of the model.

$$Min = \frac{F_1(x) - F_1^0}{F_1^{Max} - F_1^0} + \frac{F_2^0 - F_2(x)}{F_2^0 - F_2^{min}} \quad (19)$$

The results of the optimization model are shown in Tables 15-17. Table 15 shows the amount of shortage for each drug. Tables 16 and 17 show the amount of inventory for each drug in each period and the optimal allocation of each drug from each respective supplier. The model resulted in a total purchasing cost of Rp. 340,196,740 and a total purchasing value of 5,265,032.

Table 15. Amount of products shortage for each period

Drug	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Intunal Forte 25x4	0	0	0	0	0	0	0	0	0	0	0	0
Methylprednisolone 4 mg	0	0	0	0	0	0	0	0	0	0	0	0
Amplodipin 5 mg	0	0	0	0	0	0	0	0	0	0	0	84
Intunal syrup	0	0	0	0	0	0	0	0	0	0	0	0
Rhemafar 4 mg	0	0	0	0	0	0	0	0	0	0	0	0

Based on Table 15, the optimization results show a shortage of 84 units for the Amlodipine 5 mg product in period 12. This is due to a high demand of 423 units in period 12, while only 238 units were ordered, and the inventory in period 11 was 101 units, resulting in a shortage of 84 units.

Table 16. Amount of inventory for each period

Drug	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Intunal Forte 25x4	0	57	120	65	17	0	9	0	4	49	81	67
Methylprednisolone 4 mg	0	37	0	47	0	55	15	51	16	0	63	0
Amplodipin 5 mg	0	22	49	97	61	110	66	43	33	6	101	0
Intunal syrup	35	77	134	138	29	70	140	85	0	0	87	156
Rhemafar 4 mg	0	4	0	0	7	0	0	0	0	0	7	0

Based on Table 16, the optimization results, which were obtained to fulfill the objective function, show that there was a remaining quantity of 35 units of Intunal syrup in period 1. This is because the model also considered the total value of the supplier, which is calculated by multiplying each supplier's weight by the order quantity. Since Supplier 2 has a high score, an order of 90 units was placed to achieve a higher supplier score. Additionally, because inventory costs are lower than purchasing costs, 90 units are ordered for each period from Supplier 2 to qualify for the level 1 discount. This strategy helps minimize total purchasing costs and prevents shortages. Furthermore, there was a remaining quantity of 4 units of Rhemafar 4 mg in period 2 because the discount index is assumed to be the same for each period. If 85 units are ordered in period 1, meeting the minimum order for discount level 1, then in the following periods they will also order at least 85 units to match the discount level from the previous period. As a result, there will be 4 units of inventory in period 2 because 85 units will be ordered, while the demand is only 81 units.

Table 17. Amount of order allocation for each product to each supplier for each period

Drug	Supplier	Period											
		1	2	3	4	5	6	7	8	9	10	11	12
Intunal Forte 25x4	Supplier 1	72	40	40	40	40	40	40	40	40	40	40	40
	Supplier 2	80	75	80	80	80	80	73	80	40	40	40	40
	Supplier 3	80	40	40	41	80	80	40	40	40	40	40	40
Methylprednisolone 4 mg	Supplier 2	80	80	80	80	80	80	80	80	80	80	80	80
	Supplier 8	80	80	80	80	80	80	80	80	80	80	80	80
	Supplier 9	10	0	4	26	69	0	0	0	0	33	0	11
Amlodipin 5 mg	Supplier 2	100	100	100	100	100	100	100	100	100	100	100	100
	Supplier 3	4	0	50	69	69	69	69	69	69	69	69	69
	Supplier 8	0	0	0	0	0	0	0	0	0	0	23	69
	Supplier 9	0	0	0	0	0	0	0	0	0	0	0	0
Intunal Syrup	Supplier 1	0	0	0	0	0	0	0	0	0	0	0	0
	Supplier 2	90	90	90	90	90	90	90	90	90	90	90	90
	Supplier 3	50	50	53	90	90	90	90	90	90	59	83	90
Rhemafar 4 mg	Supplier 1	19	0	54	32	0	16	23	42	33	12	0	36
	Supplier 3	85	85	85	85	85	85	85	85	85	85	85	85
	Supplier 4	0	0	0	0	0	0	0	0	0	0	0	0
	Supplier 6	0	0	0	0	0	0	0	0	0	0	0	0

Based on Table 17, only 69 units of Amlodipine 5 mg were ordered from Supplier 8 in period 12. This is because the discount index in this model is assumed to be the same for each period. Therefore, if no order is placed with Supplier 8 for Amlodipine in period 1, the selected discount level only allows orders of 0-69 units (non-discounted price) for all subsequent periods. As a result, in period 12, the maximum order quantity allowed to receive the non-discounted price is 69 units.

Sensitivity Analysis

To determine the effect of parameter changes on the decision variables and objective functions of the model, a sensitivity analysis was performed. The sensitivity analysis was carried out by changing several parameters across various scenarios. We study the effects of holding cost, shortage cost, and demand in the sensitivity analysis. The model is considered sensitive if a small change in a parameter significantly affects the objective function and decision variables. The results of the sensitivity analysis on the holding cost are shown in Table 18.

Table 18. Effect of changes in holding cost parameters on objective function

Changes of scenario	Multi objective function	Purchase' total cost (Rp)	Purchase' total value
-60%	0.0851554	338,589,654	5265.032
-40%	0.0865726	339,125,338	5265.032
-20%	0.0880020	339,661,023	5265.032
0%	0.0894200	340,196,708	5265.032
20%	0.0908234	340,732,392	5265.032
40%	0.0922133	341,268,077	5265.032
60%	0.1099320	360,048,946	5408.337

Based on Table 18, changes in the holding cost parameter do not significantly affect the objective functions. When the holding cost is reduced by 20%, the total purchase cost decreases by 0.16% from the initial value and continues to decrease consistently until the -60% scenario. On the other hand, when the holding cost is increased by 20%, the total purchase cost rises by 0.16% from the initial value and continues to increase consistently until the 40% scenario. However, at the 60% scenario, the total purchase cost increases by 5.5%. From this analysis, it can be concluded that changes in the holding cost parameter are not sensitive to the objective function and decision variables. Table 19 shows the effect of shortage cost on the objective function.

Table 19. Effect of changes in shortage cost parameters on objective function

Changes of scenario	Multi objective function	Purchase' total cost (Rp)	Purchase' total value
-60%	0.0920163	339,220,238	5265.0322
-40%	0.0894201	339,545,728	5265.0322
-20%	0.0894226	339,871,218	5265.0322
0%	0.0894200	340,196,708	5265.0322
20%	0.0894200	340,522,198	5265.0322
40%	0.0894199	340,847,688	5265.0322
60%	0.0894199	341,173,177	5265.0322

Based on Table 19, changes in the shortage cost parameter do not significantly affect the objective functions. When the shortage cost is reduced by 20%, the total purchase cost decreases by 0.1% from the initial value and continues to decrease consistently until the -60% scenario. On the other hand, when the shortage cost is increased by 20%, the total purchase cost increases by 0.1% from the initial value and continues to increase consistently until the 60% scenario. From this analysis, it can be concluded that changes in the shortage cost parameter are not sensitive to the objective function and decision variables.

Table 20. Effect of changes in demand parameters on objective function

Changes of scenario	Multi objective function	Purchase' total cost (Rp)	Purchase' total value
-15%	0.12116	291,315,608	4839.262
-10%	0.10845	297,560,236	4908.858
-5%	0.09422	320,735,884	5113.360
0%	0.08942	340,196,708	5265.032
5%	0.07729	306,800,134	5522.905
10%	0.06942	326,783,037	5722.435
15%	0.07519	341,439,225	5853.818

Table 20 shows the effect of demand on the objective function. Based on the table, changing the demand parameter does not have a significant effect on the objective function. However, it significantly affects the decision variables in terms of the inventory and shortage of the drugs. When the demand parameter is decreased by 15%, the inventory of Methylprednisolone 4 mg increases by 109%. This result comes from the optimization model, which considers all unit discounts. To achieve the objective of minimizing the total purchase cost, the order allocation amount is maximized to meet the minimum threshold for level 1 discount. Therefore, even though the demand decreases, the order allocation amount remains large, exceeding the demand in order to secure the level 1 discount. When the demand parameter is decreased by 15%, the number of shortages for Amlodipine 5 mg is reduced by 100%. With the high order allocation, the demand is still fulfilled, so there will be no shortage for any drug. Additionally, due to the low holding and shortage costs, the model maximizes the order allocation to obtain the level 1 discount, thus achieving the model's objective function. As a result, when demand increases by 5% or 10%, the total cost decreases because the model takes discount levels into account. When demand rises, the order quantity increases for each supplier that meets the minimum threshold to obtain level 1 discount pricing, thereby minimizing the total purchasing cost.

Conclusions

In this research, the problems of supplier selection and order allocation at a PW company were solved using the BWM, TOPSIS, and multi-objective optimization model. Fifteen sub-criteria were used by the company to determine the supplier scores. By using the BWM and TOPSIS methods, the weight of each criterion and the ranking for each supplier can be determined. Multi-objective optimization will make it easier to determine the amount of order allocation based on the calculations carried out during the supplier selection process. For future research, incremental discounts can be added, along with the use of different discount levels for each period. Additionally, parameters that are considered fluctuating, such as demand, can be modeled as fuzzy parameters.

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