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Article

Sustainable lathe machine selection using PROMETHEE

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ABSTRACT

The manufacturing echelon of supply chains utilizes several machines to convert raw materials into finished products. Therefore, during procurement of these machines, supply chain managers are usually saddled with the problem of obtaining the best machine from a group of similar alternatives, considering multiple criteria simultaneously. The main purpose of this study is to utilize the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) for selecting the best lathe machine from a group of five (5) similar alternatives, namely Lathe 1, Lathe 2, Lathe 3, Lathe 4 and Lathe 5. Four (4) criteria were used in evaluating the machines, namely power, price, complexity, and weight, with preference weights of 0.25, 0.3, 0.25, and 0.2, respectively. The results indicated that Lathe 2 is the best alternative because it has the highest total net flows of 0.325, followed by Lathe 5, which has total net flows of 0.03. Next is Lathe 1, which has a total net flow of -0.0188, followed by Lathe 3, having a total net flow of -0.0975, and finally, Lathe 4, which is the worst ranking alternative, having a total net flow of -0.2388. Therefore, PROMETHEE proved to be a viable multi-criteria decision-making tool for selecting the most suitable lathe machine among the group of alternative machines. This study is significant because it provides a procedure for aiding supply chain managers in selecting the best alternative among a group of similar alternatives using PROMETHEE.

1. Introduction

The Supply chain managers are responsible for managing various activities within supply chain networks. There are several methods for optimally managing production processes [1, 2]. The management process is usually tedious when the correct procedure is not consistently followed, or the various components of business management are not effectively combined. This could lead to various forms of waste within the manufacturing supply chain, especially when managers cannot predict uncertainty within the supply chain [3-8]. The main components of business management are money, manpower, materials, methods, and machines. Money refers to the capital utilized in the production of goods and the offering of services. It is important for the acquisition of raw materials, personnel hiring, acquisition of machines as well as equipoising costs incurred during the operation of the supply chain. Manpower refers to the skilled and unskilled workers involved in the production of goods and rendering of services. Materials refer to the raw supplies fed into the supply chain and used to produce semi-finished or finished goods. Methods refer to the usual and recommended procedures for carrying out operations within the supply chain by established systems. Machines refer to the equipment used in converting raw materials into semi-finished or finished products [9, 10]. Machines are crucial for the profitability and survival of supply chains [11-14]. This is because rapid product output from the manufacturing echelon of supply chains is usually a result of well-running machinery, which can, in turn, provide the entire supply chain with a competitive edge [15, 16]. During procurement of machines, managers usually encounter the problem of deciding which machine is the best among alternatives. This is a complex problem because the machines must be evaluated simultaneously by considering multiple criteria. Multi-criteria decision analysis models have proven efficient in solving these decision-making problems involving evaluations based on multiple criteria. These methods can be employed in supplier selection, materials selection, production scheduling, routing, inventory management, pricing strategies, and evaluation of various product designs, to name a few. The preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) has been utilized in many decision-making problems in engineering. The methodology has been applied to the complex and strategic problem of selecting a lean manufacturing system compared to a computer-integrated manufacturing system, considering the benefits to be gained and the impact on the organization's stakeholders [17]. It has also been applied to rank and select appropriate dispatching rules for a Dual-Resource Constrained manufacturing system [18]. The methodology has been applied to manufacturing scheduling by providing the ranking of alternative schedules based on completion times [19, 21]. Furthermore, the methodology has been combined with the Bayesian method to address equipment failure uncertainty by preventive maintenance planning and failure control in the context of equipment breakdown [22]. Similarly, the method has been used to determine the optimal preventive maintenance intervals [23]. The method has been applied to the problem of selecting the optimal solution for an inverse electromagnetic scattering problem [24]. PROMETHEE has also been used to rank alternatives during assembly planning as well as select the best equipment combination for individual stations with the aid of a multi-objective grouping genetic algorithm [25, 26]. Moreover, it has been applied to the problem of choosing a predictive maintenance program within an automotive paint shop [27]. Lathe machines are machine tools that operate by rotating a cylindrical workpiece about an axis of rotation to perform various operations such as cutting, drilling, sanding, knurling, facing, deformation, and turning with the aid of a tool applied to the workpiece to create an object which is symmetrical about that axis. Lathe machines are very important machinery within major metalworking plants that produce metal products [28-30]. The main purpose of this study is to utilize PROMETHEE to select the best lathe machine from a group of similar alternatives. PROMETHEE provides the decision maker with a ranking of alternatives based on global or total net flows. The following sections describe the underlying equations of PROMETHEE, and the results of applying the equations to the lathe machine selection problem.

2. Methodology

In the PROMETHEE method, alternatives are pairwise compared in order to find the most appropriate alternative. The set of alternatives to be ranked are denoted by $A = \{a_1, a_2, \cdots, a_n\}$ and the set of criteria are denoted by $F = \{f_1, f_2, \cdots, f_m\}$. Also, denoting the evaluation of alternative a_j on criterion f_i by $f_i(a_j)$ and assuming that $f_i(a_j)$ is a numeric value. A preference matrix is generated from the data, and is used in calculating the global flows. The global pairwise preference degrees computed between all the ordered pairs of alternatives constitute the preference matrix. The global preference degrees are obtained from the criterion preference degrees by means of the weighted sum and provide the basis for deducing the global flows.

2.1 Unicriterion preference degrees

The unicriterion preference degree P_{ij}^k, which can also be denoted as $P_k(a_i, a_j)$, is calculated for each ordered pair of alternatives (a_i, a_j). This unicriterion preference degree, P_{ij}^k, depicts how much more preferred alternative a_i is to a_j based solely on criterion f_k. P_{ij}^k will be a number between 0 and 1, and is a function of $f_k(a_i) - f_k(a_j)$, the more this difference, the stronger the unicriterion preference degree. A choice between three different types of preference functions has to be made by the decision maker, which in turn determines the preference degree. Considering the linear preference function with q as the indifference threshold and p as the preference threshold, the equation for the unicriterion preference degree is given by [31, 32]:

$$P_{ij}^k = \begin{cases} 0 & \text{if} \quad f_k(a_i) - f_k(a_j) \le q \\ \frac{[f_k(a_i) - f_k(a_j) - q]}{[p - q]} & \text{if} \quad q < f_k(a_i) - f_k(a_j) < p \\ 1 & \text{if} \quad f_k(a_i) - f_k(a_j) \ge p \end{cases} \tag{1}$$

However, if a Gaussian preference function is considered the equation for the unicriterion preference degree is given by [33].

$$P_{ij}^k = \begin{cases} 1 - \exp\left(\frac{-\left(f_k(a_i) - f_k(a_j)\right)^2}{2s^2}\right) & \text{if } f_k(a_i) - f_k(a_i) \ge 0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where s is the inflexion point. P_{ij}^k and P_{ji}^k are not symmetric numbers but respect the condition $0 \le P_{ij}^k + P_{ji}^k \le 1$.

2.2 Global preference degree

After calculating the ordered unicriterion preference degrees, the global preference degree, π_{ij}, can be computed taking the weights of each criterion into account. Denoting w_k as the weight associated with the criterion f_k. If the weight respects the condition $\sum_{k=1}^{q} w_k = 1$, then the global preference degree of alternative a_i on a_j is given by [33]:

$$\pi(a_i, a_j) = \pi_{ij} = \sum_{k=1}^{q} w_j \cdot P_{ij}^k \tag{3}$$

where w_j is the weight of a criterion j, and P_{ij}^k is the unicriterion preference degree. This global preference degree lies between 0 and 1, and respects the constraint $0 \le \pi_{ij} + \pi_{ji} \le 1$. Therefore, $\forall i : \pi_{ii} = 0$.

2.3 Global flows

The ordered preference degrees are summarized into a unique score for each alternative, using the positive and negative flows. Denoting by $\Phi^+(a_i)$ the positive flows of alternative a_i and $\Phi^-(a_i)$ the negative flows of alternative a_i. Their values can be computed as follows [33]:

$$\Phi^+(a_i) = \frac{\sum_{j=1}^{n} \pi_{ij}}{n-1} \tag{4}$$

$$\Phi^-(a_i) = \frac{\sum_{j=1}^{n} \pi_{ji}}{n-1} \tag{5}$$

where π_{ij} is the global preference degree of alternative a_i on a_j, and π_{ji} is the global preference degree of alternative a_j on a_i.

2.4 Net flows

The net flows, $\Phi(a_i)$, summarizes the positive and negative flows with one formula given by [33]:

$$\Phi(a_i) = \Phi^+(a_i) - \Phi^-(a_i) \quad (6)$$

where $\Phi^+(a_i)$ is the positive flow of alternative a_i and $\Phi^-(a_i)$ is the negative flow of alternative a_i. The net flow is a number between -1 and 1. The higher this number is, the better the alternative will be.

3. Results and discussion

This section presents the results of applying the PROMETHEE method to the lathe machine selection problem. The objective is to rank five (5) different lathe machines based on four (4) criteria, namely: power, price, complexity, weight. The power criterion is to be maximized, the price criterion is to be minimized, the complexity criterion is to be minimized, and the weight criterion is to be minimized for each of the lathe machines. Table 1 shows the raw performance data of the various lathe machines and the selection criteria.

Table 1. The performance of the five (5) lathe machines evaluated on four (4) criteria

	Power (hp)	Price ($)	Complexity	Weight (lb)
Objective	**MAX**	**MIN**	**MIN**	**MIN**
Lathe 1	30	1500	Extreme	1000
Lathe 2	40	1380	Medium	1200
Lathe 3	50	2500	High	1500
Lathe 4	60	4750	Medium	2400
Lathe 5	100	6300	Low	3100

Figure 1 shows the numeric values of the complexity criteria on a complexity scale. From Figure 1, low complexity corresponds to a numeric value of 2, medium complexity corresponds to a numeric value of 4, high complexity corresponds to a numeric value of 6, and extreme complexity corresponds to a numeric value of 8, on the complexity scale.

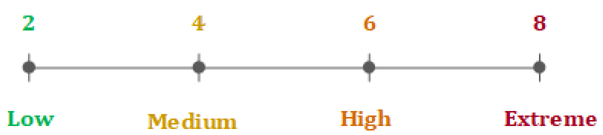

Figure 1. Numeric complexity scale

Therefore, from the performance data in Table 1 and the numerical scale in Figure 1, Lathe 1 has a complexity of 8, Lathe 2 has a complexity of 4, Lathe 3 has a complexity of 6, Lathe 4 has a complexity of 4, and Lathe 5 has a complexity of 2. Table 2 shows the preference parameters for all the criteria. From Table 2, the power criterion has a linear preference function, a weight of 0.25, an indifference threshold of 20, and a preference threshold of 40. Also, the price criterion has a linear preference function, a weight of 0.3, an indifference threshold of 600, and a preference threshold of 1000. Furthermore, the complexity criterion has a linear preference function, a weight of 0.25, an indifference threshold of 1, and a preference threshold of 2. Moreover, the weight criterion has a linear preference function, a weight of 0.2, an indifference threshold of 500, and a preference threshold of 1000. Table 3 shows the differences between evaluations of the lathes on power criterion.

Table 2. Criteria preference parameters

Criterion	Function	Weight, w_i	Indifference Threshold, q_i	Preference Threshold, p_i
Power	Linear	0.25	20	40
Price	Linear	0.3	600	1000
Complexity	Linear	0.25	1	2
Weight	Linear	0.2	500	1000

Table 3. Differences between evaluations of the lathes on power criterion

	Lathe 1	Lathe 2	Lathe 3	Lathe 4	Lathe 5
Lathe 1	0	-10	-20	-30	-70
Lathe 2	10	0	-10	-20	-60
Lathe 3	20	10	0	-10	-50
Lathe 4	30	20	10	0	-40
Lathe 5	70	60	50	40	0

From Table 3, considering the power criterion that has to be maximized, all lathes compared with themselves result in a difference of 0. Lathe 1 compared with Lathe 2 results in a difference of 10. Lathe 1 compared with Lathe 3 results in a difference of 20. Lathe 1 compared with Lathe 4 results in a difference of 30. Finally, Lathe 1 compared with Lathe 5 results in a difference of 70. Table 4 shows the differences between evaluations of the lathes on price criterion.

Table 4. Differences between evaluations of the lathes on price criterion

	Lathe 1	Lathe 2	Lathe 3	Lathe 4	Lathe 5
Lathe 1	0	120	-1000	-3250	-4800
Lathe 2	-120	0	-1120	-3370	-4920
Lathe 3	1000	1120	0	-2250	-3800
Lathe 4	3250	3370	2250	0	-1550
Lathe 5	4800	4920	3800	1550	0

From Table 4, considering the price criterion which has to be minimized, all lathes compared with themselves result in a difference of 0. Lathe 1 compared with Lathe 2 results in a difference of 120. Lathe 1 compared with Lathe 3 results in a difference of 1000. Lathe 1 compared with Lathe 4 results in a difference of 3250. Finally, Lathe 1 compared with Lathe 5 results in a difference of 4800. Table 5 shows the differences between evaluations of the lathes on complexity criterion.

Table 5. Differences between evaluations of the lathes on complexity criterion

	Lathe 1	Lathe 2	Lathe 3	Lathe 4	Lathe 5
Lathe 1	0	4	2	4	6
Lathe 2	-4	0	-2	0	2
Lathe 3	-2	2	0	2	4
Lathe 4	-4	0	-2	0	2
Lathe 5	-6	-2	-4	-2	0

From Table 5, considering the complexity criterion which has to be minimized, all lathes compared with themselves result in a difference of 0. Lathe 1 compared with Lathe 2 results in a difference of 120. Lathe 1 compared with Lathe 3 results in a difference of 1000. Lathe 1 compared with Lathe 4 results in a difference of 3250. Finally, Lathe 1 compared with Lathe 5 results in a difference of 4800. Table 6 shows the differences between evaluations of the lathes on weight criterion.

Table 6. Differences between evaluations of the lathes on weight criterion

	Lathe 1	Lathe 2	Lathe 3	Lathe 4	Lathe 5
Lathe 1	0	-200	-500	-1400	-2100
Lathe 2	200	0	-300	-1200	-1900
Lathe 3	500	300	0	-900	-1600
Lathe 4	1400	1200	900	0	-700
Lathe 5	2100	1900	1600	700	0

From Table 6, considering the weight criterion which has to be minimized, all lathes compared with themselves result in a difference of 0. Lathe 1 compared with Lathe 2 results in a difference of 200. Lathe 1 compared with Lathe 3 results in a difference of 500. Lathe 1 compared with Lathe 4 results in a difference of 1400. Finally, Lathe 1 compared with Lathe 5 results in a difference of 2100. Table 7 shows the pairwise comparison matrix for the power criterion. From Table 7, comparing the differences with the preference and indifference thresholds based on the power criterion, Lathe 4 has a preference degree of 0.5 over Lathe 1. Moreover, the preference degree of Lathe 5 over Lathe 1, Lathe 2, Lathe 3, and Lathe 4 is 1. This means that based on the power criterion, Lathe 5 is preferred. Table 8 shows the pairwise comparison matrix for the price criterion.

Table 7. Pairwise comparison matrix for the power criterion

	Lathe 1	Lathe 2	Lathe 3	Lathe 4	Lathe 5
Lathe 1	0	0	0	0	0
Lathe 2	0	0	0	0	0
Lathe 3	0	0	0	0	0
Lathe 4	0.5	0	0	0	0
Lathe 5	1	1	1	1	0

Table 8. Pairwise comparison matrix for the price criterion

	Lathe 1	Lathe 2	Lathe 3	Lathe 4	Lathe 5
Lathe 1	0	0	1	1	1
Lathe 2	0	0	1	1	1
Lathe 3	0	0	0	1	1
Lathe 4	0	0	0	0	1
Lathe 5	0	0	0	0	0

From Table 8, comparing the differences with the preference and indifference thresholds based on the price criterion, Lathe 1 has a preference degree of 1 over Lathe 3, Lathe 4 and Lathe 5. Moreover, the preference degree of Lathe 2 over Lathe 3, Lathe 4, Lathe 5 is 1. Again, the preference degree of Lathe 3 over Lathe 4 and Lathe 5 is 1. Furthermore, the preference degree of Lathe 4 over Lathe 5 is 1. This means that based on the price criterion Lathe 1 and Lathe 2 are preferred over Lathe 3, Lathe 4 and Lathe 5. While Lathe 3 is preferred over Lathe 4 and Lathe 5, and Lathe 4 is preferred over Lathe 5. Table 9 shows the pairwise comparison matrix for the complexity criterion.

Table 9. Pairwise comparison matrix for the complexity criterion

	Lathe 1	Lathe 2	Lathe 3	Lathe 4	Lathe 5
Lathe 1	0	0	0	0	0
Lathe 2	1	0	1	0	0
Lathe 3	1	0	0	0	0
Lathe 4	1	0	1	0	0
Lathe 5	1	1	1	1	0

From Table 9, comparing the differences with the preference and indifference thresholds based on the complexity criterion, when the preference degree is 0, it indicates that the difference in price is lower than the indifference threshold, and there is no difference between the two lathe machines being compared. On the other hand, when the preference degree is 1, it indicates that the difference between the two lathe machines being compared is greater than the preference threshold; therefore, there is a difference between the two lathe machines being compared. Table 10 shows the pairwise comparison matrix for the weight criterion.

Table 10. Pairwise comparison matrix for the weight criterion

	Lathe 1	Lathe 2	Lathe 3	Lathe 4	Lathe 5
Lathe 1	0	0	0	1	1
Lathe 2	0	0	0	1	1
Lathe 3	0	0	0	0.8	1
Lathe 4	0	0	0	0	0.4
Lathe 5	0	0	0	0	0

From Table 10, comparing the differences with the preference and indifference thresholds based on the weight criterion, when the preference degree is 0, it indicates that the difference in price is lower than the indifference threshold, and there is no difference between the two lathe machines being compared. When the preference degree is between 0 and 1, it implies that the difference between the lathe machines being compared is between the indifference and preference thresholds. On the other hand, when the preference degree is 1, it indicates that the difference between the two lathe machines being compared is greater than the preference threshold. Therefore, there is a difference between the two lathe machines being compared. Table 11 shows the pairwise preference matrix considering all the criteria and their weights.

Table 11. Pairwise preference matrix

	Lathe 1	Lathe 2	Lathe 3	Lathe 4	Lathe 5
Lathe 1	0	0	0.3	0.5	0.5
Lathe 2	0.25	0	0.55	0.5	0.5
Lathe 3	0.25	0	0	0.46	0.5
Lathe 4	0.375	0	0.25	0	0.38
Lathe 5	0.5	0.5	0.5	0.5	0

From Table 11, the total positive flows, total negative flows, and total net flows for each lathe machine were calculated, and these data are shown in Table 12.

Table 12. Total positive flows, total negative flows, and total net flows

Lathes	Total Positive Flows	Total Negative Flows	Total Net Flows
Lathe 1	0.325	0.34375	-0.0188
Lathe 2	0.45	0.125	0.325
Lathe 3	0.3025	0.4	-0.0975
Lathe 4	0.25125	0.49	-0.2388
Lathe 5	0.5	0.47	0.03

From Table 12, the total positive flows were calculated by averaging all the row preference degrees of a lathe compared to other lathes, excluding the preference degree of the lathe compared with itself. The total negative flows were calculated by averaging all the column preference degrees of a lathe, excluding the preference degree on the diagonal. The total net flows were obtained by subtracting the negative flows from the positive flows. Figure 2 is a plot of total net flows versus lathe machine type, and it shows the ranking of the lathe machines based on the total net flows.

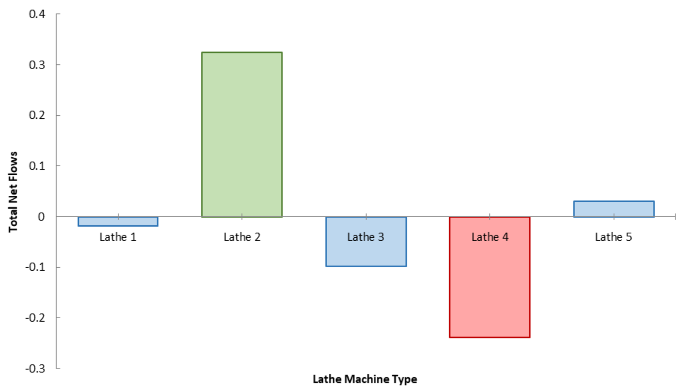

Figure 2. Plot of total net flows versus lathe machine type

From Figure 2, Lathe 2 is the best alternative because it has the highest total net flows of 0.325, followed by Lathe 5, which has total net flows of 0.03. Next is Lathe 1, which has a total net flow of -0.0188, followed by Lathe 3, having a total net flow of -0.0975, and finally, Lathe 4, which is the worst ranking alternative, having a total net flow of -0.2388. This provides the ranking of the various lathe machines under consideration based on power, price, complexity, and weight criteria with linear preference functions.

4. Conclusion

During the procurement of machines for manufacturing, managers are faced with the problem of selecting the best machine among similar alternatives. The machine selection problem is complex because decisions usually have to be made based on more than one criterion. This study utilizes PROMETHEE to select the best lathe machine from a group of five similar alternatives, namely Lathe 1, Lathe 2, Lathe 3, Lathe 4, and Lathe 5. The machines were evaluated based on criteria such as power, price, complexity, and weight, having preference weights of 0.25, 0.3, 0.25, and 0.2, respectively. The results indicated that Lathe 2 is the best alternative because it has the highest total net flows of 0.325, followed by Lathe 5, which has total net flows of 0.03. Next is Lathe 1, which has a total net flow of -0.0188, followed by Lathe 3, having a total net flow of -0.0975, and finally, Lathe 4, which is the worst ranking alternative, having a total net flow of -0.2388. The study provides a procedure for selecting the best alternative among a group of similar alternatives using PROMETHEE. For further research, other multi-criteria decision analysis methods and method combinations can be utilized to select the best machine among a group of machines during procurement. Also, the performance of each alternative can be investigated considering a situation where the preference functions of each criterion is not linear.

Ethical issue

The author is aware of and complies with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The author adheres to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the authors.

Conflict of interest

The author declares no potential conflict of interest.

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