Int J Adv Manuf Technol (2017) 88:1485–1493
DOI 10.1007/s00170-016-8878-8

ORIGINAL ARTICLE

Implementation of fuzzy TOPSIS methodology in selection of procedural approach for facility layout planning

Parveen Sharma [1] · **Sandeep Singhal** [1]

Received: 27 November 2014 / Accepted: 5 May 2016 / Published online: 14 May 2016

Abstract The present study deals with the selection of procedural approach for the handling of facility layout problem (FLP). Most of the designers always try to design the layout to fulfill the practical need on the shop floor in an effective way. The procedural approach is also a way to tackle the layout problems practically. It has always been a difficult decision to select the appropriate solution approach under several selected factors. In this paper, we have demonstrated a selection of the best procedural approach for the FLP with some selected factors. In this context, we have considered some important factors such as initial data required (IDR), use of charts (UC), use of graphs and diagrams (UGD), future expansion considered (FEC), constraints considered (CC), procedure implementation (PI), and material handling equipment selection consideration (MHC). Modified digital logic (MDL) is used to assign weight to the selected factors. Fuzzy logic-based multiple attribute decision making (MADM) approach is applied for the selection. The Muther's approach is found to be the most suitable alternative with the selected factors.

Keywords Facility layout problem · Procedural approach · Modified digital logic · Multiple attribute decision making · Fuzzy TOPSIS

✉ Parveen Sharma
i.parveensharma@gmail.com

[1] Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, India

1 Introduction

The productivity of any organization is being affected by several factors. Some of the crucial factors are available machines, skill of workers, material handling equipments, layout of the industry, etc. These factors directly or indirectly have a role in increasing or decreasing the production [1]. Facility layout planning includes an arrangement of the available facilities on the shop floor in such a way to get maximum utilization from them and to get the enhanced output. While establishing any industry, design of the layout is most important and crucial part. Higher work-in-process inventory, longer queues, overloading of material handling equipments, etc. are possible outcomes due to poor layout of facility [2–4]. A good quality layout has a fast movement of equipments on the shop floor without any obstacles, less inventory, better utilization of resources, etc. [5].

Facility layout problem can be tackled with computerized techniques, algorithmic approaches, and also with procedural approaches. The solution provided with computerized techniques needs further modifications before implementation on the shop floor. For algorithmic approaches, the designer must have knowledge of mathematics; generally, this becomes the reason the designer mostly chooses to ignore implementing these techniques. According to Yang et al. [5] and Chien [6], from the practical perspective, the procedural approach is very effective for designing the layouts. The layout design problem is divided into several steps in the procedural approaches [7, 8]. However, in such approaches, the final solution depends upon the designer's ability and practical knowledge of the industry [9, 10]. The solution provided by the approaches discussed above should have the possibility of implementation. In addition, computerized and algorithmic approaches generally do not consider all the design criteria (i.e., quality-based criterions, flexibility, maintenance, etc.) while solving the layout problems [8, 11, 12]. However, it becomes quite possible to consider all criteria in the procedural approaches at the same time [9, 13].

The procedural approaches followed by most layout designers are Nadler's procedure (NP), Immer's procedure (IP), Muther's procedure (MP), Apple's procedure (AP), and Reed's procedure (RP). All of them have been discussed by researchers briefly, but still there is a need to compare these approaches by considering some selected factors. This gap is fulfilled by the present research by comparing these approaches with the multiple attribute decision making (MADM) technique. MADM approaches are usually employed for handling such problems where more than two alternatives are needed to be compared on the basis of selected criterions [14–16]. A variety of methods comes under the MADM category. Some of them are graph theory and matrix approach (GTMA), analytic hierarchy process (AHP), vlsekriterijumska optimisacija I kompromisno resenje (VIKOR), simple additive weighting (SAW), and technique for order preference by similarity to ideal solution (TOPSIS) [15]. These approaches have been applied by various researchers in vast areas such as social science decisions, manufacturing process, financial decisions, and engineering problems. The MADM approaches also work on crisp values of attribute and this fact makes them suitable to apply in the selection of advanced technologies as there is no clear boundary. Most of the attributes depend on the views of various decision makers. Such selection problems can be dealt with fuzzy set theories aid with MADM approaches. It has always been a difficult decision to select the appropriate solution approach for the facility layout under several selected factors [17–19].

Çebi and Otay [20] implemented the fuzzy TOPSIS methodology in facility location selection problems. Mardani et al. [21], in 2015, presented a two-decade review from 1994 to 2014 on fuzzy multiple criteria decision-making techniques; their study highlighted the application of fuzzy DEMATEL, fuzzy VIKOR, fuzzy AHP, and fuzzy TOPSIS approaches for solving the problem of facility layout. A comparison between the fuzzy AHP and fuzzy TOPSIS methods has been carried out by Ertuğrul and Karakaşoğlu [22]. Torfi et al. [23] applied fuzzy AHP to determine the relative weights of selected layout factors and then applied fuzzy TOPSIS for ranking the available alternatives of the layout. An integrated AHP-VIKOR methodology has been applied to deal with the facility layout design problems of three different industries by Shokri et al. [24]. Farahani et al. [25] carried out a survey based on the multiple criteria facility location problems. A facility layout problem (FLP) design always consists of several unclear and less précised criteria weights. According to Torfi et al. [23] and Ataci et al. [26], fuzzy AHP and fuzzy TOPSIS are the more preferable techniques when our problem consists of vague and inaccurate criteria weights and performance ratings. It is revealed from past investigations that the application of fuzzy TOPSIS was well utilized and reported with improved FLP design. Among the other fuzzy-based MADM methods, the fuzzy TOPSIS approach is quite simpler and easier to implement in such research problems, and versatile too.

The aim of the present work is to implement fuzzy TOPSIS to select the best available procedural approach as none of the available literature demonstrates such a selection approach. The method selected and conclusions arrived upon in the present research paper will help the designer to make appropriate decisions with respect to the methodology adopted for the procedure selection for designing the layout under some selected factors. The paper is organized as follows: in the first section, an introduction is represented; description of selected factors is given in Sect. 2; an overview of the utilized methodology and mathematical description of the proposed method are presented in Sects. 3 and 4, respectively; and a discussion of the results is in Sect. 5 followed by the conclusions.

2 Factors for evaluation of procedural approaches

We identified some crucial factors based on a discussion with a panel of experts from the industry as well as institution. The description of these factors is given below:

Factor	Description
Initial data required (IDR)	It is the data required at the initial stage of the procedure. IDR is very important in the procedure; if the initial data are very much in quantity, it becomes difficult to handle it, and there may be chances of error during the procedure implementation.
Use of charts (UC)	Charting is a way to collect and represent the initial input data effectively. It is easier to handle data in the form of charts. Use of chart for initial input data is always very helpful for a clear understanding of the problem.
Use of graphs and diagrams (UGD)	Once the solution procedure for any layout problem is initiated, representation of data with the help of a graph and a diagram is also an effectual way to handle the problem easily. Comparison of the available data is also possible simply with graphs and diagrams in the middle stage of the solution procedure.
Future expansion consideration (FEC)	The design of the layout must not only be for the present but also for future possibilities. For increasing production, it always becomes necessary to add the facilities to the

	one currently existing; therefore, future expansion must be considered in the layout solution tool.
Constraints considered (CC)	Layout solution approaches must have a realistic view, and practically on the shop floor there are many obstructions, limitations, special installation requirements for machines, etc. Therefore, it becomes very important to consider constraints while designing the layout.
Procedure implementation (PI)	This factor is very crucial for any layout solution tool. It represents the possibility of implementation of the final designed layout.
Material handling equipment selection consideration (MHC)	Material handling equipment is also very important; selection of the best equipment always helps in enhancing the productivity, so the layout solution tool must consider this factor while designing.

Each selected factor has its own importance for facility layout. IDR should be minimized for saving the design time of layout. UC is essential for easy handling and understanding of the IDR for any layout. Increase in IDR also increases UC for simplifying the procedure. UGD affects the process stages of any procedure once the solution procedure is initiated. FEC directly affects the PI; if the layout is designed by considering future expansion, then implementation of the final layout should be possible for the success of the design. CC and PI also directly affect each other; if CC is not considered while designing the layout, there may be a chance that implementation is not possible for the final design. MHC is also a very important factor in the layout design procedure; if equipment for material handling is selected at the design level of layout, it directly impacts profitability of any industry.

3 Methodology used

3.1 Modified digital logic

All the factors or properties do not have equal impact for the selection of appropriate technology for the design of the facility layout and we cannot assign equal weights to them [27]. Thus, it becomes necessary to find out the priority of each factor. MDL is such a well-known technique to estimate the weights for factors in such conditions [28, 29]. Initial priority as 1 for less, 2 for equally, and 3 for more important properties are assigned according to expert opinion. After assigning the priorities, a decision matrix is formed by pairwise comparison. Prior to formation of the matrix, we need to estimate the number of possible positive decisions as $N = n(n-1)/n$, where n is the number of attributes/technological parameters. The further summation of all positive decisions (P) for a particular parameter on normalization leads to the final weight (W_j) as

$$W_j = \frac{P_j}{\sum_{j=1}^{n} P_j} \quad (1)$$

3.2 Fuzzy logic

When there is a problem with a lack of precision and there is also no clear boundary between the system and the surroundings, the fuzzy approach is introduced to tackle such problems [22, 30]. The fuzzy approach also deals with problems where it seems tough to distinguish between the non-member and the member objects of the set. This approach was employed for the multiple criteria decision making by Belleman and Zadeh [31]. It is based on a fuzzy set theory and a fuzzy set can be defined as a set comprised of a membership function within the interval *[0, 1]*, which describes the extent of relevance of an element for being a member of the set linguistic variables, which are used for all comparisons initially. Further, fuzzy values are assigned to these linguistic variables in order to have comparable numerical values without any ambiguity using appropriate membership functions.

In this study, trapezoidal fuzzy numbers (a_1, a_2, a_3, a_4) for $a_1, a_2, a_3, a_4 \in \mathrm{R}$; $a_1 \le a_2 \le a_3 \le a_4$ are used. Figure 1 graphically illustrates a trapezoidal fuzzy number. The membership function $\mu_a(x)$ of the trapezoidal fuzzy number is defined as

$$\mu_a(x) = \begin{cases} \frac{x-a_1}{a_2-a_1}, x \in [a_1, a_2] \\ 1, x \in [a_2, a_3] \\ \frac{a_4-x}{a_4-a_3}, x \in [a_3, a_4] \\ 0, \textit{otherwise} \end{cases} \quad (2)$$

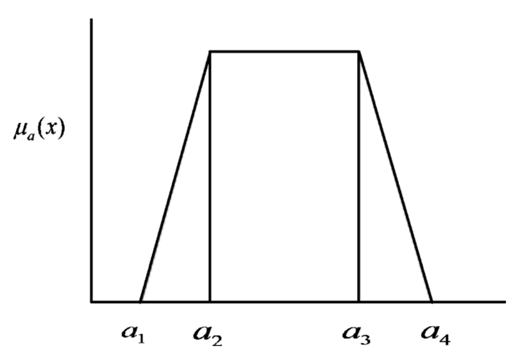

Fig. 1 Trapezoidal fuzzy number

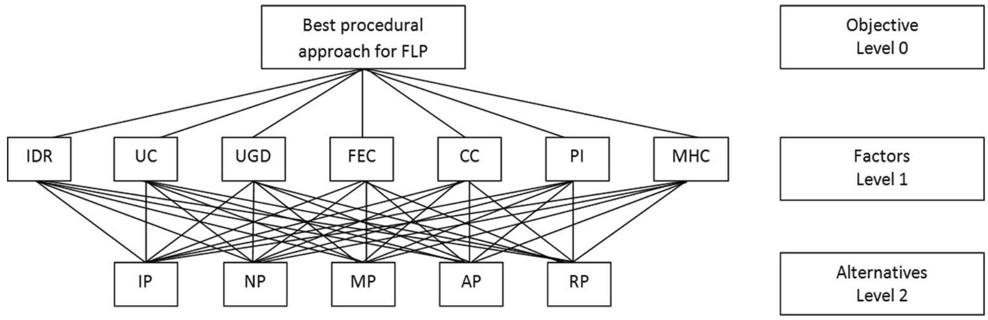

Fig. 2 A schematic hierarchy for selection of the best procedural approach

3.3 Technique for order preference by similarity to ideal solution method

Hwang and Yoon in 1981 suggested the technique for order preference by similarity to ideal solution (TOPSIS) model [32]. TOPSIS implies that a decision matrix having *n* properties and *m* material can be assumed to be the problem of *n* dimensional hyper plane having *m* points whose location is given by the values of their attributes. It evaluates the Euclidean distance between the given alternative and the positive ideal solution and the negative ideal solution, respectively. The one having the least distance from the positive ideal is considered as the best possible alternative and the large distance from the negative ideal solution.

4 Proposed methodology

In this section, we proposed a fuzzy TOPSIS approach for the selection of the best alternative of procedural approach for the facility layout design. Following are the steps of the adopted methodology:

Step 1—MDL weights calculation

The first step is to calculate the MDL weights (W_j) for each factor. Weights of each selected factors are as discussed in Sect. 3.1.

Step 2—Define linguistic terms, corresponding fuzzy numbers, and relevant membership function

In order to compare all the available alternatives for each factor, a set of fuzzy terms is required. All fuzzy terms are assigned by the decision maker and also responsible for the intracriterion comparisons of the alternatives.

Step 3—Formation of the decision matrix

The next step is to determine the decision matrix. If '*m*' be the alternatives and '*n*' be the factors, then, for '*k*' number of decision makers in the proposed model and for C_j factors, the aggregated fuzzy rating is as

$$x_{ijk} = \{x_{ijk1}, x_{ijk2}, x_{ijk3}, x_{ijk4}\},$$

for $i = 1, 2, \ldots m$; $j = 1, 2, \ldots k$, x_{ijk} is calculated as [33]:

$$\begin{cases} x_{ij1} = \min_k \{a_{ijk1}\} \\ x_{ij2} = \frac{1}{k} \sum a_{ijk2} \\ x_{ij3} = \frac{1}{k} \sum a_{ijk3} \\ x_{ij4} = \max_k \{a_{ijk4}\} \end{cases} \quad (3)$$

The obtained decision matrix (*D*) is as

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \ddots & x_{mn} \end{bmatrix}$$

Table 1 Weights using MDL

Factors	IDR	UC	UGD	FEC	CC	PI	MHC	Positive decision	Weight	Rank
IDR	2	1	1	3	1	1	1	8	0.098	6
UC	3	2	1	3	3	3	3	16	0.195	2
UGD	3	3	2	3	3	3	3	18	0.220	1
FEC	1	1	1	2	1	1	1	6	0.073	7
CC	1	1	1	3	2	1	1	8	0.098	5
PI	3	1	1	3	3	2	3	14	0.171	3
MHC	3	1	1	3	3	1	2	12	0.146	4
Sum								82		

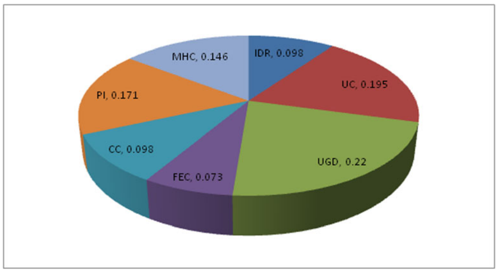

Fig. 3 Weight assigned to all the selected factors

Step 4—Normalization

All quantities being compared must be on the same scale; this is the basic necessity of any comparison. Therefore, the next step is to normalize the aggregated fuzzy rating. Two kinds of situation can arise, one is properties with higher desired values and the other is properties with lower desired values. For both the case, normalization is done as

$$\mu_{ij} = \left(\frac{x_{ij1}}{x^+_{ij1}}, \frac{x_{ij2}}{x^+_{ij2}}, \frac{x_{ij3}}{x^+_{ij3}}, \frac{x_{ij4}}{x^+_{ij4}}\right), j \in J_1 \quad (4)$$

$$\mu_{ij} = \left(\frac{x^-_{ij1}}{x_{ij1}}, \frac{x^-_{ij2}}{x_{ij2}}, \frac{x^-_{ij3}}{x_{ij3}}, \frac{x^-_{ij4}}{x_{ij4}}\right), j \in J_2 \quad (5)$$

where $x^+_{ij4} = \max(x_{ij4}), j \in J_1$ and $x^-_{ij1} = \min(x_{ij1}), j \in J_2$

J_1 corresponds to the higher best value criterion and J_2 corresponds to the lower best value criterion.

Step 5—Defuzzification

It is performed to obtain the crisp values for each factor corresponding to each alternative. Defuzzification provides a quantitative value for the linguistic variables. Crisp values are obtained by the following Eq. (6):

$$f_{ij} = Defuzz(x_{ij}) = \frac{\int \mu(x).xdx}{\int \mu(x).dx}$$
$$= \frac{\int_{x_{ij1}}^{x_{ij2}} \left({(x-x_{ij1})} / {(x_{ij2}-x_{ij1})} \right).xdx + \int_{x_{ij2}}^{x_{ij3}} xdx + \int_{x_{ij3}}^{x_{ij4}} \left({(x_{ij4}-x)} / {(x_{ij4}-x_{ij3})} \right).xdx}{\int_{x_{ij1}}^{x_{ij2}} \left({(x-x_{ij1})} / {(x_{ij2}-x_{ij1})} \right)dx + \int_{x_{ij2}}^{x_{ij3}} dx + \int_{x_{ij3}}^{x_{ij4}} \left({(x_{ij4}-x)} / {(x_{ij4}-x_{ij3})} \right)dx}$$
$$= \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + \left({}^1/_3\right)\left(x_{ij4}-x_{ij3}\right)^2 + \left({}^1/_3\right)\left(x_{ij2}-x_{ij1}\right)^2}{-x_{ij1}-x_{ij2} + x_{ij3} + x_{ij4}} \quad (6)$$

Table 2 Linguistic variables and corresponding fuzzy number

Linguistic variables	Fuzzy number
Exceptionally high (EH)	(0.8, 0.9, 1.0, 1.0)
Very high (VH)	(0.7, 0.8, 0.8, 0.9)
High (H)	(0.5, 0.6, 0.7, 0.8)
Above average (AA)	(0.4, 0.5, 0.5, 0.6)
Average (A)	(0.2, 0.3, 0.4, 0.5)
Very low (VL)	(0.1, 0.2, 0.2, 0.3)
Extremely low (EL)	(0.0, 0.0, 0.1, 0.2)

The values obtained from these equations are incorporated with the MDL weightage to calculate the final ranking using the TOPSIS method as given below.

Step 6—Normalize the matrix.

Data provided in the above step has to be normalized; we need to develop a normalized decision matrix. All the factors are converted into unique and common sense numbers.

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{i=1}^{m} \left(f_{ij}\right)^2}}; \forall_j \quad (7)$$

Step 7—Calculate the weighted normalized decision matrix.

In the next step, the weighted normalized decision matrix needs to be constructed.

$$V_{ij} = \left[r_{ij}\right]_{m\times n} \times \left[W_j\right]^{diagonal}_{n\times m} \quad (8)$$

Step 8—Calculate the positive ideal and negative ideal solutions.

Two ideal solutions known as positive ideal and negative ideal solution are of high concern in the decision-making process. There is a need to stay away as far as possible from the negative ideal solution and as close as possible to the positive ideal solution.

The positive ideal solution V^+_j and negative ideal solution V^-_j are as given below:

$$V^+_j = \left\{\left(\max V_{ij}, j \in J_1\right), \left(\min V_{ij}, j \in J_2\right), i = 1, 2, 3.....m\right\}; \forall j \quad (9)$$

$$V^-_j = \left\{\left(\min V_{ij}, j \in J_1\right), \left(\max V_{ij}, j \in J_2\right), i = 1, 2, 3.....m\right\}; \forall j \quad (10)$$

where J_1 and J_2 represents the higher best and lower best criteria respectively.

Table 3 Linguistic decision matrix for procedural approaches for all evaluation criteria

Factors	Immer's procedure (IP)	Nadler's procedure (NP)	Muther's procedure (MP)	Apple's procedure (AP)	Reed's procedure (RP)
IDR	VH	VH	A	AA	H
UC	VL	VL	H	A	A
UGD	VL	VL	H	A	A
FEC	EL	EL	EL	EL	VH
CC	EL	VL	H	A	A
PI	EL	EL	VH	A	A
MHC	VL	VL	A	EH	A

Step 9—Calculate the separation d_i^+ and d_i^- from the positive ideal solution and negative ideal solution respectively.

$$d_i^+ = \left[\sum_{j=1}^{n} \left(V_{ij} - V_j^+\right)^2\right]^{0.5}, i = 1, 2, 3, ...m \quad (11)$$

$$d_i^- = \left[\sum_{j=1}^{n} \left(V_{ij} - V_j^-\right)^2\right]^{0.5}, i = 1, 2, 3, ...m \quad (12)$$

In Eq. (11), d_i^+ is the separation of alternative i from the positive ideal solution and in Eq. (12), d_i^- is the separation of alternative i from the negative ideal solution.

Step 10—Calculate the rank index.

The relative closeness to the ideal solution for each alternative is calculated as follows:

$$C_i^+ = \frac{d_i^-}{d_i^- + d_i^+}$$

Alternative with higher rank index (C_i^+) is preferred.

5 Results and discussion

In the previous section, we discussed about the solution approaches for facility layout problem and the main important factors which affects the selection of best procedural approach for FLP. During the present research, the quality opinions from experts of similar field have been acquired in the necessary stages of the design. There were four experts in our panel. The selection criterion was based upon the two experts from the sound academic profession and two from the industrial background. Various MADM approaches are available, which can be implemented for selecting the best alternative. In the present study, fuzzy TOPSIS is applied for the ranking of the selected procedural approaches. It is observed as the best suitable technique for the present case condition. The priority of each factor is decided by implementing the MDL approach and then the fuzzy approach utilized to assign fuzzy values to considered linguistic variables. The TOPSIS method was used to provide solution which has the least distance from the positive ideal and the largest distance from the negative ideal solution.

The systematic hierarchy of the present research problem is demonstrated in Fig. 2 (selection of best procedural approach for FLP). Our objective is indicated by the level 0 (best procedural approach for FLP); it has to be selected from the available alternatives as shown at level 2. Different factors which affect the selection are given at level 1 in Fig. 2. Interdependency of all the alternatives on these important factors shows the complexity of the problem. All the factors have their individual importance.

Table 4 Essential parameters for evaluation and corresponding fuzzy ratings

Factors	Immer's procedure (IP)	Nadler's procedure (NP)	Muther's procedure (MP)	Apple's procedure (AP)	Reed's procedure (RP)
IDR	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.2, 0.3, 0.4, 0.5)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
UC	(0.1, 0.2, 0.2, 0.3)	(0.1, 0.2, 0.2, 0.3)	(0.5, 0.6, 0.7, 0.8)	(0.2, 0.3, 0.4, 0.5)	(0.2, 0.3, 0.4, 0.5)
UGD	(0.1, 0.2, 0.2, 0.3)	(0.1, 0.2, 0.2, 0.3)	(0.5, 0.6, 0.7, 0.8)	(0.2, 0.3, 0.4, 0.5)	(0.2, 0.3, 0.4, 0.5)
FEC	(0.0, 0.0, 0.1, 0.2)	(0.0, 0.0, 0.1, 0.2)	(0.0, 0.0, 0.1, 0.2)	(0.0, 0.0, 0.1, 0.2)	(0.7, 0.8, 0.8, 0.9)
CC	(0.0, 0.0, 0.1, 0.2)	(0.1, 0.2, 0.2, 0.3)	(0.5, 0.6, 0.7, 0.8)	(0.2, 0.3, 0.4, 0.5)	(0.2, 0.3, 0.4, 0.5)
PI	(0.0, 0.0, 0.1, 0.2)	(0.0, 0.0, 0.1, 0.2)	(0.7, 0.8, 0.8, 0.9)	(0.2, 0.3, 0.4, 0.5)	(0.2, 0.3, 0.4, 0.5)
MHC	(0.1, 0.2, 0.2, 0.3)	(0.1, 0.2, 0.2, 0.3)	(0.2, 0.3, 0.4, 0.5)	(0.8, 0.9, 1.0, 1.0)	(0.2, 0.3, 0.4, 0.5)

Table 5 Calculated crisp values for assigned fuzzy rates

Factors	Immer's procedure (IP)	Nadler's procedure (NP)	Muther's procedure (MP)	Apple's procedure (AP)	Reed's procedure (RP)
IDR	4.167	4.167	1.833	2.667	3.333
UC	0.292	0.292	0.833	0.458	0.458
UGD	0.292	0.292	0.833	0.458	0.458
FEC	0.086	0.086	0.086	0.086	0.926
CC	0.097	0.292	0.833	0.458	0.458
PI	0.086	0.086	0.926	0.407	0.407
MHC	0.233	0.256	0.367	0.944	0.367

So, it becomes necessary to prioritize these factors. Pairwise comparison is made and 1, 2, and 3 are allotted for relatively least, equal, or more important parameter, respectively. On the basis of the pairwise comparison, relative decision matrix is formed and calculations for weights for all the selected factors are summarized in Table 1. Among the selected factors, "use of graphs and charts" was found to be the most influential factor for selecting the procedural approach, followed by the "use of charts." Figure 3 illustrates the weight assigned to all the selected factors.

Comparison of all the alternatives for each factor is the next step of this research. There is a need of a hypothetical scale to compile all the comparative data. The fuzzy logic approach works well in this kind of problems; therefore, fuzzy is applied in the present case. It compares the alternatives on the basis of linguistic variables. These variables are further converted into fuzzy numbers as given in Table 2. In this table, exceptionally high (EH) represents the best value (most desirable) and extremely low (EL) represents the worth value (most undesirable). Linguistic decision matrix and their corresponding fuzzy ratings for the present case are demonstrated in Tables 3 and 4, respectively. Fuzzy values are normalized using Eqs. (4) and (5), and then finally converted into crisp values using Eq. (6). Calculated crisp values obtained after the normalization of aggregated fuzzy ratings are shown in Table 5. The TOPSIS approach is applied (Eqs. (7, 8, 9, 10, 11, and 12) on these quantitative numbers to obtain the rank indices of all alternatives. Table 6 shows the crisp values with associated weights of the factors. Table 7 represents the distance from the positive ideal solution d_i^+ and the negative ideal solution d_i^- and rank index C_i^+ for the present case.

Calculation predicts that Muther's approach is the most suitable alternative for solving the facility layout problems, with the selected factors and their weightage. Apple's approach is the most suitable alternative after Muther's approach and stands at second position. The rank along with overall priority is as follows: MP (0.781) > AP (0.579) > NP (0.274) > IP (0.258) > RP (0.136). The factors which are used in the present study are weighted in the following order: UGD (0.220) > UC (0.195) > PI (0.171) > MHC (0.146) > CC (0.098) > IDR (0.098) > FEC (0.073).

The analytic hierarchy process (AHP) also has been applied on the same problem. Table 8 demonstrates the outcomes of the implementation. The results of the AHP came out similar to fuzzy TOPSIS as Muther's approach is the most suitable alternative.

Several benefits of the proposed method are as follows: it is a simple process and easy to use. The number of steps remains the same regardless of the number of factors. On the other hand, some limitations also exist such as problems due to interdependence between factors and alternatives. The selection of factors depends upon the expert's knowledge.

Table 6 Crisp values with associated weights of the factors

Weights	0.098 IDR	0.195 UC	0.22 UGD	0.073 FEC	0.098 CC	0.171 PI	0.146 MHC
IP	4.167	0.292	0.292	0.086	0.097	0.086	0.233
NP	4.167	0.292	0.292	0.086	0.292	0.086	0.256
MP	1.833	0.833	0.833	0.086	0.833	0.926	0.367
AP	2.667	0.458	0.458	0.086	0.458	0.407	0.944
RP	3.333	0.458	0.458	0.926	0.458	0.407	0.367

Table 7 Distance from positive ideal solution and negative ideal solution and rank index

	d_i^+	d_i^-	Rank index	Rank
IP	0.227358	0.079088	0.258082	4
NP	0.221811	0.083598	0.273725	3
MP	0.076151	0.271937	0.781231	1
AP	0.133436	0.183378	0.578819	2
RP	0.292276	0.046042	0.13609	5

Table 8 Overall priority vectors and AHP ranking

	IDR	UC	UGD	FEC	CC	PI	MHC	Overall priority vector	Rank
IP	0.314	0.074	0.074	0.072	0.042	0.048	0.063	0.088	5
NP	0.314	0.074	0.074	0.072	0.088	0.048	0.090	0.098	4
MP	0.061	0.462	0.462	0.128	0.471	0.487	0.176	0.355	1
AP	0.120	0.195	0.195	0.072	0.200	0.209	0.494	0.232	2
RP	0.193	0.195	0.195	0.655	0.200	0.209	0.176	0.228	3

6 Conclusions

The MADM approach is employed for the selection of the best procedural approach for solving facility layout problem. Feasibility of the fuzzy TOPSIS method is proposed in the present study for selecting the best procedural approach for FLP. Modified digital logic (MDL) is applied to calculate the weightage of all the considered factors for evaluating the alternatives. Use of graphs and diagrams is found to be the most and future expansion consideration is found as the least critical factor. Priority order for procedural approaches is determined by using the fuzzy TOPSIS approach incorporated with the MDL weights. The Muther's approach is found to be the most suitable alternative for handling the FLP. AP and NP are found at second and third positions, respectively.

References

1. Altuntas S, Selim H (2012) Facility layout using weighted association rule-based data mining algorithms: evaluation with simulation. Expert Sys Appl 39(1):3–13
2. Jajodia S, Minis I, Harhalakis G, Proth JM (1992) CLASS: computerized layout solutions using simulated annealing. Int J Production Res 30(1):95–108
3. Sahin R, Turkbey O (2009) A simulated annealing algorithm to find approximate Pareto optimal solutions for the multi-objective facility layout problem. Int J Adv Manuf Technol 41(9-10):1003–1018
4. Altuntas S, Islier A (2010) A solution approach to assembly line balancing problem with task related constraints and an application at an enterprise. Pamukkale University J Eng Sci 16(1):29–44
5. Yang T, Su CT, Hsu YR (2000) Systematic layout planning: a study on semiconductor wafer fabrication facilities. Int J Oper Prod Manag 20(11):1359–1371
6. Chien TK (2004) An empirical study of facility layout using a modified SLP procedure. J Manuf Technol Manag 15(6):455–465
7. Aksarayli M, Altuntas S (2009) The comparison of layout arrangements for the material flow ordering planning in production systems through simulation analysis. PAJES 15(2):203–214
8. Hadi-Vencheh A, Mohamadghasemi A (2013) An integrated AHP–NLP methodology for facility layout design. J Manuf Syst 32(1): 40–45
9. Azadeh A, Izadbakhsh HR (2008) A multi-variate/multi-attribute approach for plant layout design. Int J Ind Eng Theory Appl Pract 15(2):143–154
10. Yang T, Kuo C (2003) A hierarchical AHP/DEA methodology for the facilities layout design problem. Eur J Oper Res 147(1):128–136
11. Yang T, Hung CC (2007) Multiple-attribute decision making methods for plant layout design problem. Robot Comput Integr Manuf 23(1):126–137
12. Ertay T, Ruan D, Tuzkaya UR (2006) Integrating data envelopment analysis and analytic hierarchy for the facility layout design in manufacturing systems. Inf Sci 176(3):237–262
13. Muther R (1973) Systematic layout planning. CBI Publishing Co, Boston
14. Pratyyush S, Jian-Bo Y (1998) Multiple criteria decision support in engineering design. Springer Verlag, Berlin
15. Yang L, Deuse J, Jiang P (2013) Multiple-attribute decision-making approach for an energy-efficient facility layout design. Int J Adv Manuf Technol 66(5-8):795–807
16. Altuntas S, Dereli T, Selim H (2013) Fuzzy weighted association rule based solution approaches to facility layout problem in cellular manufacturing system. Int J Ind Syst Eng 15(3):253–271
17. Altuntas S, Selim H, Dereli T (2014) A fuzzy DEMATEL-based solution approach for facility layout problem: a case study. Int J Adv Manuf Technol 73(5-8):749–771
18. Ripon KSN, Torresen J (2014) Integrated job shop scheduling and layout planning: a hybrid evolutionary method for optimizing multiple objectives. Evol Syst 5(2):121–132
19. Rao RV, Davim JP (2008) A decision-making framework model for material selection using a combined multiple attribute decision-making method. Int J Adv Manuf Technol 35(7-8):751–760
20. Çebi F, Otay İ (2015) Multi-criteria and multi-stage facility location selection under interval type-2 fuzzy environment: a case study for a cement factory. Int J Comput Intell Sys 8(2):330–344
21. Mardani A, Jusoh A, Zavadskas EK (2015) Fuzzy multiple criteria decision-making techniques and applications—two decades review from 1994 to 2014. Expert Sys Appl 42(8):4126–4148
22. Ertuğrul İ, Karakaşoğlu N (2008) Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection. Int J Adv Manuf Technol 39(7-8):783–795
23. Torfi F, Farahani RZ, Rezapour S (2010) Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the alternatives. Appl Soft Comput 10(2):520–528
24. Shokri H, Ashjari B, Saberi M, Yoon JH (2013) An integrated AHP. VIKOR methodology for facility layout design. Ind Eng Manag Sys 12(4):389–405
25. Farahani RZ, SteadieSeifi M, Asgari N (2010) Multiple criteria facility location problems: a survey. Appl Math Model 34(7): 1689–1709

26. Ataei E, Branch A (2013) Application of TOPSIS and fuzzy TOPSIS methods for plant layout design. World Appl Sci J 23(12):48–53
27. Shahin A, Poormostafa M (2011) Facility layout simulation and optimization: an integration of advanced quality and decision making tools and techniques. Mod Appl Sci 5(4):95–111
28. Ardeshirilajimi A, Aghanouri A, Abedian A, Milani A (2014) An exponential placement method for materials selection. Int J Adv Manuf Technol 78(1-4):641–650
29. Jahan A, Mustapha F, Sapuan SM, Ismail MY, Bahraminasab M (2012) A framework for weighting of criteria in ranking stage of material selection process. Int J Adv Manuf Technol 58(1-4):411–420
30. Zadeh LA (1965) Fuzzy sets. Inf Control 8(3):338–353
31. Bellman RE, Zadeh LA (1970) Decision-making in a fuzzy environment. Manag Sci 17(4):B-141-164
32. Deng H, Yeh CH, Willis RJ (2000) Inter-company comparison using modified TOPSIS with objective weights. Comput Oper Res 27(10):963–973
33. Mehrjerdi YZ (2013) Hierarchical multi-criteria risk-benefit analysis in fuzzy environment. Appl Soft Comput 13(1):590–599