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METAHEURISTICS-BASED NESTING OF PARTS IN SHEET METAL CUTTING OPERATION

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Abstract: *Nesting of regular and irregular shaped parts in a sheet metal having constrained boundary so as to maximize effective utilization of material with minimum wastage imposes a challenging task to the metal cutting industries. To resolve the problem, this paper presents the applications of six popular metaheuristics, i.e. artificial bee colony, ant colony optimization, particle swarm optimization, firefly algorithm, differential evolution and teaching-learning-based optimization (TLBO) algorithm with an objective to maximize effective utilization ratio during metal cutting operation. For all the metaheuristics, the considered parts are optimally allocated in the given sheet metal based on bottom left fill algorithm to minimize the corresponding nested height. It is observed that TLBO algorithm supersedes the others with respect to effective utilization ratio, nested height and computational effort. A comparative analysis using values of t-statistic also proves the uniqueness of this algorithm over the others in efficiently solving the nesting problems for regular and irregular shaped parts during sheet metal cutting operation.*

Key words: *Sheet metal, Nesting, Cutting, Metaheuristic, Effective utilization ratio.*

1. Introduction

Sheet metal cutting operation results in generation of huge volume of waste material in the form of scrap while positioning various part configurations in the sheet. The sheet metal industries mainly focus on determining the optimal layouts of parts having dissimilar shapes within the available sheet boundary so as to maximize utilization of materials. Maximum utilization of sheet metal can effectively reduce scrap while considerably decreasing the expenses during sheet metal cutting operation. These scraps are sometimes hazardous, causing injuries or environmental menaces. In order to reduce wastage of material and efficiently utilize the sheet

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metal, an effective nesting strategy is essential for arranging different parts in the sheet before cutting them. Nesting is a classical approach to attain an optimal layout of parts in non-overlapping configuration in a given sheet with same thickness and material so that minimal wastage can be guaranteed. Nesting can be classified as one-dimensional, two-dimensional and three-dimensional. In two-dimensional nesting, two-dimensional parts are positioned in the sheet metal assuming its width to be fixed with an aim of minimizing nested height of the parts (Joshi et al., 2012). Minimization of nested height of the parts ultimately results in reduction of the collective area involved in the entire nesting process. Nesting is widely applied in various manufacturing industries, like shipbuilding, clothing, furniture etc. (Ramesh & Baskar, 2015). In earlier days, experienced workers of the concerned manufacturing industries were responsible to decide the optimal layouts, but in most of the cases, they were unsuccessful to arrive at the satisfactory solutions as the manual nesting process is tedious and time consuming (Kumar & Singh, 2008). The nesting problem is often characterized by the inherent complexity associated with the shapes and sizes of the parts, computational intricacy and non-overlapping configurations. Presently, there are scarcities of efficient nesting algorithms in the manufacturing industries for locating complex parts which hinder in achieving the maximum productivity during sheet metal cutting operation. Nesting algorithms, like rectangular enclosure method, bottom left fill (BLF) algorithm and numerous heuristic techniques have commonly been applied to determine effective nesting patterns, but only few of them have been capable of providing satisfactory solutions (Ramesh & Baskar, 2015). Several nesting software are also available in the market, but in most of the cases, they do not provide optimal layouts which may lead to unwanted wastage of materials. Mathematical programming techniques have been a popular choice among the researchers while exploring the solutions for nesting problems for regular and irregular shaped objects. However, those techniques are also not suitable for nesting of complex shaped parts. In order to solve complicated nesting problems, many metaheuristic algorithms, like Tabu search (TS) (Dechampai et al., 2021), genetic algorithm (GA) (Huang et al., 2020), simulated annealing (SA) (Rausch et al., 2021) etc. have been adopted. Even though these techniques can determine effective layouts, they are quite similar to manual methods with respect to computational time (Ramesh & Baskar, 2015). Therefore, the above-identified drawbacks of the earlier adopted techniques have led to the development and implementation of improved mathematical tools to effectively determine the optimal layouts of parts in the sheet metals before the actual cutting operation.

In this paper, an attempt is put forward to compare the applicability and optimization performance of six popular metaheuristics, i.e. artificial bee colony (ABC), ant colony optimization (ACO), particle swarm optimization (PSO), firefly algorithm (FA), differential evolution (DE) and teaching-learning-based optimization (TLBO) algorithm while solving two-dimensional nesting problems for regular and irregular shaped objects during sheet metal cutting operation. The optimization performance of these metaheuristics is validated with respect to nested height, effective utilization ratio (EUR) of the sheet metal and computational time. The paired *t*-tests are also performed to identify the uniqueness of the adopted algorithms.

The organization of this paper is as follows: Section 1 describes the nesting process and its importance in sheet metal cutting industries; Section 2 presents a review of the existing literature; and Section 3 provides the problem statement along with the mathematical details of BLF and metaheuristic algorithms. Section 4 deals with the applications of the considered metaheuristics to solve the nesting problems for regular and irregular shaped parts. Finally, conclusions are drawn in Section 5.

2. Literature review

In metal cutting industries, nesting of regular and irregular shaped objects in sheets to minimize the trimming loss is a challenging issue. In this direction, several metaheuristic-based algorithms have been proposed by the past researchers along with the deployment of suitable placement strategies to identify the optimal nesting patterns for having maximum utilization of the material. Table 1 provides a list of the nesting problems considered, and placement strategies and optimization tools adopted by the past researchers to resolve this issue.

Table 1. List of the nesting problems, placement strategies and optimization tools

Name of author(s)	Problem	Placement strategy	Optimization tool(s)
Cheng et al. (2021)	2D cutting stock problem in construction industry	BLF	Auto-tuning symbiotic organisms search algorithm
Daoden (2020)	2D irregularly shaped stock cutting problem	No-fit polygon	Shuffled leaping algorithm
Daoden and Thaiupathump (2017)	2D rectangular packing problem	BLF	Shuffled leaping algorithm
Dechanmpai et al. (2021)	2D irregularly shaped stock cutting problem	BLF	TS
Dogde et al. (2021)	2D cutting stock problem	BLF	DNA-sticker algorithm
Erozan and Çalışkan (2019)	2D orthogonal packing problem	BLF	GA
Firat and Alpashan (2020)	2D rectangular packing problem	BLF, no-fit polygon	SA
Hopper and Turton (2001)	2D rectangular packing problem	BLF	GA, SA, naive evolution, local search heuristic
Huang and Wang (2020)	2D rectangular packing problem	Rectangular layout strategy	GA
Labaadi et al. (2020)	2D bin packing problem	BLF	Crow search algorithm
Li et al. (2021)	2D rectangular packing problem	BLF	Hybrid adaptive GA
Qin et al. (2021)	2D nesting problem of irregular shaped parts	No-fit polygon, central expansion strategy	GA, SA
Ramesh and Bhaskar et al. (2015)	2D cutting stock problem	-	GA

Table 1. Contd.

Name of author(s)	Problem	Placement strategy	Optimization tool(s)
Rao et al. (2021)	Irregular shaped parts packing problem	No-fit polygon	Hybrid beam search, TS
Rausch et al. (2021)	2D irregularly shaped stock cutting problem	BLF	SA
Reddy (2016)	2D regular and irregular shaped cutting problem	BLF	GA
Sakaguchi et al. (2020)	2D nesting and scheduling of sheet metal parts	-	Environment-adaptive GA
Sherif et al. (2014)	Nesting and cutting sequence optimization in laser cutting process	BLF	SA
Struckmeier and León (2019)	2D nesting problem in flatbed laser-cutting machine	BLF	Two variants of an evolutionary algorithm
Valvo (2017)	2D nesting problem of irregular rectangular pieces	BLF, no-fit polygon	Evolutionary computation, GA, evolution strategy, SA, estimation of distribution, DE, PSO
Virik and Singh (2018)	2D nesting of non-guillotine irregular rectangular pieces	BLF	Cuckoo search algorithm, bat algorithm
Wang et al. (2021)	2D bin packing problem	BLF	GA

From the review of the above-cited literature, it can be clearly revealed that nesting of regular/irregular shaped parts in sheet metals is a complex problem and various metaheuristic algorithms, like GA, SA, DE, ACO and other hybrid techniques have already been considered for obtaining effective solutions for varying nesting problems. Among the placement strategies, BLF algorithm has been the most popular choice. It is also observed that no single algorithm can provide effective nesting solution within reasonable computational time. To the best of the authors' knowledge, no research work has been conducted to contrast the optimization performance of the adopted algorithms in a single decision making framework. Hence, this paper attempts to solve two-dimensional nesting problems for regular and irregular shaped objects in standard sheet metals with the generation of optimal patterns using six well-accepted metaheuristic algorithms, i.e. ABC, ACO, PSO, FA, DE and TLBO while employing BLF algorithm as the placement strategy to ensure effective and closer packing of the parts. The EUR values are computed for the optimal layouts of the regular and irregular shaped parts generated using all the considered algorithms, and are compared with that of randomly allocated parts (RAP) in the sheet. The AutoCAD software is utilized here to position the two-dimensional parts in the sheet metal and develop the optimal layouts as identified by different metaheuristic algorithms. The uniqueness of these six algorithms is validated using paired t-tests.

3. Methods and problem statement

3.1. Problem statement

This paper aims to solve two-dimensional nesting problems for regular and irregular shaped objects to be cut from sheet metals of fixed dimensions to achieve higher productivity along with maximum material utilization. In order to resolve these problems, six metaheuristic algorithms are applied to obtain the optimal patterns of the parts to be positioned in the sheet metals of fixed width. The optimal pattern should have the minimum nested height of the parts. The minimum nested height would also provide minimum collective area in nesting while increasing the EUR value. The EUR value is the parameter for evaluating the nesting efficiency of the considered algorithms. The placement of regular and irregular shaped objects in the sheet metal to develop the optimal pattern is accomplished using BLF algorithm subject to three restrictions, i.e. a) no parts are placed outside the boundary of the sheet metal, b) none of the parts should overlap each other and (c) height of the parts placed in the sheet is minimum. Thus, the nesting problem can be formulated as below:

Minimize L (1)

Subject to

$X_i \leq L - l_i,\ i = 1,\ldots,N$ (2)

$Y_i \leq W - w_i,\ i = 1,\ldots,N$ (3)

$$\beta_{i,j,k}(X_j - X_i) + \alpha_{i,j,k}(Y_j - Y_i) \leq \delta_{i,j,k} + M(1 - a_{i,j,k}) \quad (4)$$

$$\sum_{k=1}^{m_{i,j}} a_{i,j,k} \geq 1, a_{i,j,k} \in \{0,1\}, X_i, Y_j \geq 0$$

where N is the total number of parts to be nested, M is a large positive number and $a_{i,j,k}$ is a binary variable associated with each part. The value of $a_{i,j,k} = 1$ signifies that j^{th} part is separated from i^{th} part by the line defined by k^{th} edge of the sheet metal; otherwise, it takes a value of 0. On the other hand, X_i and Y_i respectively represent X and Y coordinates of the bottom left corner of i^{th} part, l_i and w_i are respectively the length and width of i^{th} part, and L and W are respectively the height of the nested parts and width of the sheet metal. The objective function of Eq. (1), which needs to be minimized, signifies attainment of the minimum height of nested parts. Equations (2) and (3) are the constraints assuring placement of the parts strictly inside the sheet metal. Equation (4) prevents overlapping of the parts and the expression $(\beta_{i,j,k}(X_j - X_i) + \alpha_{i,j,k}(Y_j - Y_i) = \delta_{i,j,k})$ denotes equation of the line including k^{th} term of $m_{i,j}$ edges of the sheet metal.

3.2. BLF algorithm

The positioning-based heuristics, like bottom-left (BL) and BLF algorithms are the common techniques to pack rectangles in the sheet metal. The BLF algorithm is one of the improved versions of BL algorithm, which consists of placing parts into its lowest possible position (Hopper & Turton, 2001). In BL algorithm, the objects are shifted from the extreme top right corner towards the bottom left position alternately. The inability of this algorithm to fill up the available spaces obtained from the prior arrangement of the parts is its major drawback, while BLF algorithm is capable of filling up those spaces effectively. The strategy applied in BLF algorithm consists of placing the parts from the extreme bottom left position resulting in closer packing of objects as compared to BL algorithm. The placement strategy of BLF algorithm helps to minimize the nested height while placing the parts one by one, selecting the left-most feasible position in the sheet metal. Hence, compared to BL algorithm, BLF algorithm results in denser packing patterns. Moreover, the application of BLF algorithm as a placement strategy largely reduces the run times of the applied metaheuristics while generating high speed feasible solutions. This algorithm is simple to implement as compared to other nesting algorithms that generate good solutions. However, its time complexity is a serious problem. The steps involved in BLF algorithm are as follows (Xie et al., 2007):

Step 1: Select the parts with similar width.

Step 2: Place larger parts in the bottom left corner.

Step 3: For every nested part, allocate the remaining parts on its top.

Step 4: Minimize the rectangular enclosure by shifting the parts towards the bottom-left corner of the sheet metal.

Step 5: Repeat the above steps until the column is completely filled up by the parts.

Step 6: The column is remounted.

Step7: All the possible arrangements of the parts are attempted through re-nesting.

Step 8: Again fill up the column with the parts.

Step 9: Nest the unprocessed parts following step (1).

Step 10: Nest the subsequent columns until the entire process is completed.

3.3. Metaheuristic algorithms

Since the last two decades, a wide variety of metaheuristic algorithms, like GA, ACO, PSO, DE, ABC, FA, SA, TS and TLBO has been emerged out, and they have been gaining increasing popularity in solving complex optimization problems. These metaheuristic algorithms are more adaptive and intelligent as compared to heuristic techniques which are dependent on their computational ability based on trial and error method (Yang, 2014). The term 'meta' in metaheuristic denotes 'higher level' and these algorithms can achieve better results than simple heuristics. All the metaheuristic algorithms consist of attributes of randomization and local search approach. The randomization feature of these algorithms assists in searching out solutions from local to global scale. Hence, these algorithms are highly capable of arriving at the global optimal solutions. Any metaheuristic algorithm has two main components, i.e. intensification and diversification. In intensification, exploitation of information is carried out assuming that the current good solution can be found out in a particular region. Diversification creates varying solutions in order to explore the search space on a global scale (Talbi, 2009). Metaheuristic algorithms, like ACO, ABC, PSO, FA, DE and TLBO are categorized as population-based search techniques as they employ a set of strings or multiple particles to ensure global optimality. On the other hand, single solution-based approaches, like SA, guided local search etc. are those techniques which determine the global optimal solution based on improving a single candidate solution (Manda et al., 2012).The metaheuristic algorithms employ the following procedural steps to arrive at the optimal solutions (Khajehzadeh et al., 2011):

Step 1: In the search domain, set the population with random values.

Step 2: For each individual of the population, compute its fitness value.

Step 3: Operators, like crossover, mutation etc. are applied to generate new populations through reproduction of the preferred individuals.

Step 4: Go to step (2), until the criterion for termination is reached.

4. Metaheuristic-based nesting of parts

This paper applies six metaheuristic algorithms to solve two-dimensional nesting problems to determine effective nesting patterns for regular and irregular shaped parts during sheet metal cutting operations. In order to validate the nesting performance of the considered algorithms, two different problems for nesting of two-dimensional regular and irregular parts are considered here. In the first problem, an attempt is put forward to search out the optimal nesting pattern for 22 two-dimensional regular shaped parts in a sheet metal with dimension 100×120 mm. On the other hand, in the second problem, 22 irregular shaped parts are effectively nested in a sheet metal of 300×400 mm dimension. The configurations of the two-dimensional regular shaped parts to be nested are shown in Figure 1. These are the most commonly utilized shapes (although their dimensions may vary) for sheet metal cutting/punching operations.

The optimal patterns of the parts obtained from simulation of the six metaheuristic algorithms are positioned in the sheet metal based on BLF algorithm. While placing those parts, the nesting height should be minimized and width of the sheet is kept fixed with an objective of minimizing the collective area involved in the nesting process. The performance of arranging parts in the sheet metal is expressed with respect to EUR value, which can be defined as the ratio of the sum of areas of the parts placed in the sheet metal to the total area of the sheet metal. It can be denoted as:

$$\text{Effective utilization ratio (EUR)} = \frac{\sum_{i=1}^{N} a_i}{a_s} \qquad (5)$$

where a_i is the area of i^{th} object to be nested and a_s is the total area of the sheet metal.

For implementation of the considered metaheuristic algorithms, the corresponding computer codes are developed in Matlab 2013a in 4.00 GB RAM, 2.9 GHz processor and 32-bit operating platform. To validate the optimization performance of these metaheuristics, the derived solutions are compared with the RAP in the sheet metal. The following values are set based on trial and error method for various algorithm-specific parameters to derive the optimal solutions (experiments performed by the past researchers also help in adjusting their values):

ABC algorithm: Number of iterations = 1000, swarm size = 300, number of onlooker bees employed = 50% of swarm size, number of cycles = 500, number of scouts per cycle = 1, limit = 50 and number of employed bees = 50% of swarm size.

ACO algorithm: Number of iterations = 1000, sample size = 40, intensification factor = 0.5 and deviation distance ratio = 1.

PSO algorithm: Number of iterations = 1000, population size = 300, inertia weight factor = 0.65, and acceleration coefficients = 1.65 and 1.75

FA: Number of iterations = 1000, number of fireflies = 300, light absorption coefficient = 1, initial randomness = 0.91, randomness factor = 0.92 and randomness reduction = 0.75.

DE algorithm: Number of iterations = 1000, population size = 300, lower bound of scaling factor = 0.2, upper bound of scaling factor = 0.8 and crossover probability = 0.9.

TLBO algorithm: Number of iterations = 1000 and population size = 300.

4.1. Regular shaped parts

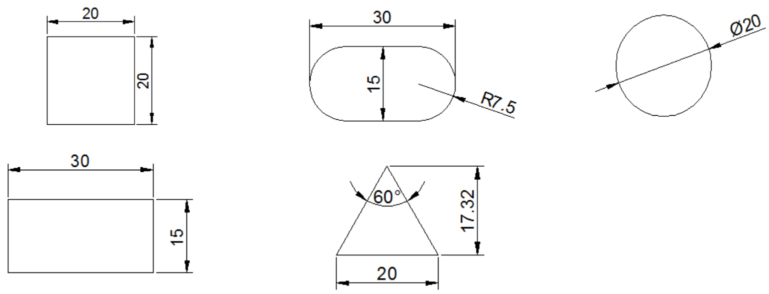


Figure 1. Regular shaped parts

In this problem, two-dimensional regular shaped parts, as shown in Figure 1, are taken into consideration for searching out the optimal nesting pattern while subsequently placing them in a sheet metal having fixed dimension of 100×120 mm. Now, the optimal patterns for these regular shaped parts are determined using all the metaheuristic algorithms, as presented in Figure 2. The BLF algorithm is applied here as the placement strategy to position these objects in the sheet metal. This placement strategy ensures better packing of parts so that the collective area involved in the nesting process is minimized. In Figure 2, the positions of the regular shaped objects using RAP are also portrayed which do not consider application of any algorithm for their allocations. It can be observed that the minimum nested height of 73.7 mm is obtained in TLBO algorithm, whereas, the maximum nested height of 85.13 mm is attained in RAP. The ABC, PSO, FA and DE algorithms provide those heights as 78.2, 77.65, 79.83, and 77.04 mm respectively. The ACO algorithm with a nested height of 80 mm performs worst in comparison to other metaheuristic algorithms. Thus, there are 6.10, 8.55, 5.36, 8.32, 4.53 and 15.51% reductions in the nested height in TLBO algorithm as compared to ABC, ACO, PSO, FA, DE and RAP techniques respectively. The computed EUR values and computational times required to develop the corresponding nesting patterns by these algorithms are provided in Table 2. It is interesting to note that among all the algorithms under consideration, the calculated EUR value based on TLBO algorithm is the maximum along with the lowest computational time. Thus, it can be propounded that TLBO algorithm excels over the others with respect to height of the nested parts, EUR value and computational time involved. The values of the nested height while placing the regular shaped objects in the given sheet metal obtained using the metaheuristic algorithms and RAP are compared in Figure 3. It reveals that TLBO algorithm outperforms the other techniques with respect to minimum nested height.

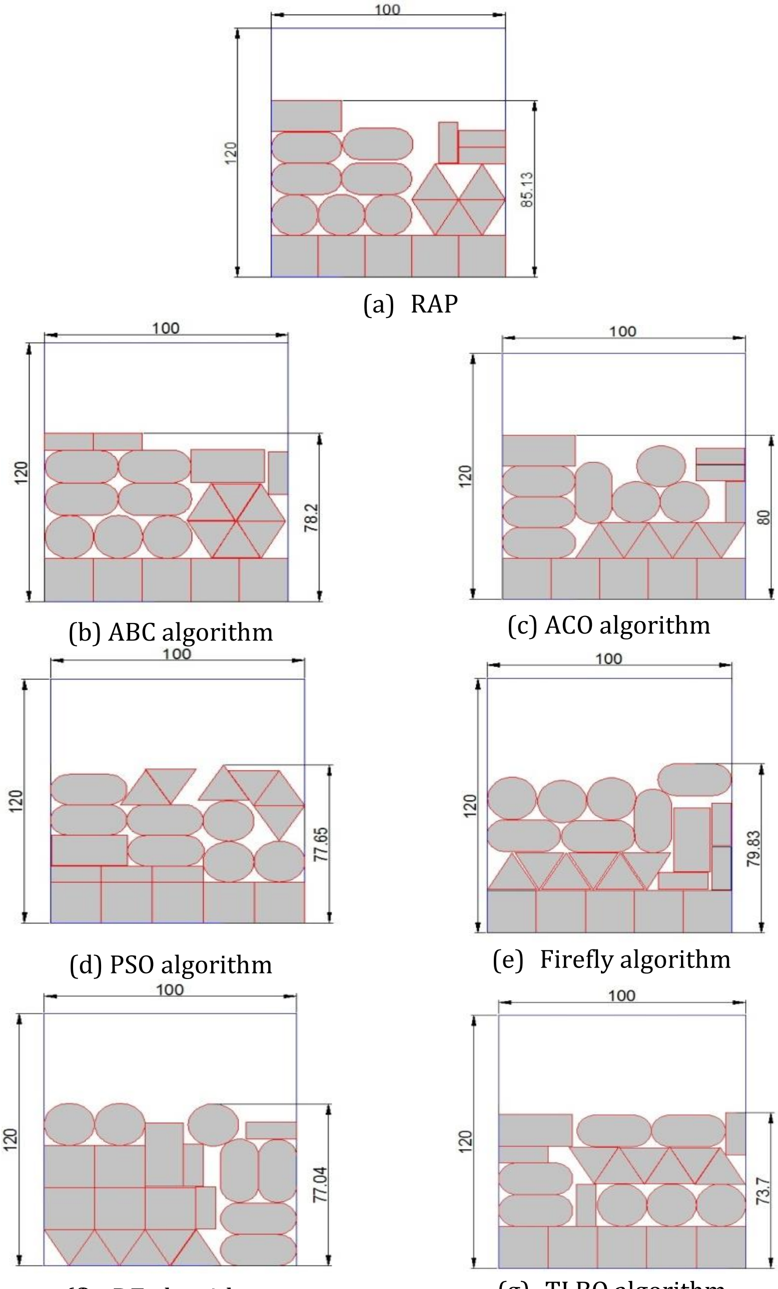
4.2. Irregular shaped parts

This problem consists of finding out the optimal nesting pattern for two-dimensional irregular shaped parts in a sheet metal having fixed dimension of 300×400 mm. The optimal patterns derived by the six metaheuristics are exhibited in Figure 4. The calculated values of EUR and computational times for these algorithms are compared in Table 3. It can be observed that the most effective nesting pattern is provided by TLBO algorithm with minimum height of the nested parts as 224.53 mm while arranging them in the given sheet metal. The PSO algorithm provides the maximum nested height of 258.57 mm, while DE, FA, ABC and ACO algorithms perform moderately. These nested heights for different layouts as obtained by the considered algorithms are shown in Figure 5. From Figures 4 and 5, it can be revealed that TLBO algorithm achieves 10.61, 7.65, 12.93, 1.53, 3.70 and 13.78% reductions in the nested height against ABC, ACO, PSO, FA, DE and RAP techniques respectively. Among the considered metaheuristics, it can be noticed that PSO algorithm performs worst with respect to the nested height of the irregular shaped parts and EUR value. For both the nesting problems, ABC algorithm consumes maximum computational time to derive the optimal layouts of parts as compared to other algorithms.

As mentioned earlier, this paper emphasizes on solving two-dimensional nesting problems to identify the optimal patterns for regular and irregular shaped objects during sheet metal cutting operation using six popular metaheuristic algorithms. Those effective nesting patterns would assist in minimizing the scrap while reducing trimming losses to minimize the overall production cost in sheet metal industries. The convergence diagrams of the nested heights for 1000 iterations for all the six metaheuristics considering packing of regular and irregular shaped objects are depicted in Figure 6. For both the problems, it is observed that TLBO algorithm excels over the others with respect to minimum nested height and computational time. It takes only 15-20 iterations in reaching at the minimum nested height, whereas, the other algorithms consume few more iterations to derive the optimal solutions. The TLBO algorithm is an efficient, simple and competent technique to achieve the global optimal solutions with less computational effort, having minimum algorithm-specific parameters, i.e. population size and number of iterations. The other adopted algorithms need more computational memory and have numerous algorithmic parameters, which if not tuned correctly, may result in local optimal solution with high computational effort. In order to confirm uniqueness of TLBO algorithm over the other metaheuristics, two-tailed paired t-tests are performed for both the packing problems with the following null hypothesis and alternative hypothesis:

H_0(Null hypothesis): Population means for two algorithms are equal ($\mu_1 = \mu_2$).

H_α(Alternate hypothesis): Population means for two algorithms are unequal ($\mu_1 \neq \mu_2$).



(a) RAP

(b) ABC algorithm

(c) ACO algorithm

(d) PSO algorithm

(e) Firefly algorithm

(f) DE algorithm

(g) TLBO algorithm

Figure 2. Optimal layouts for regular shaped parts using different metaheuristics

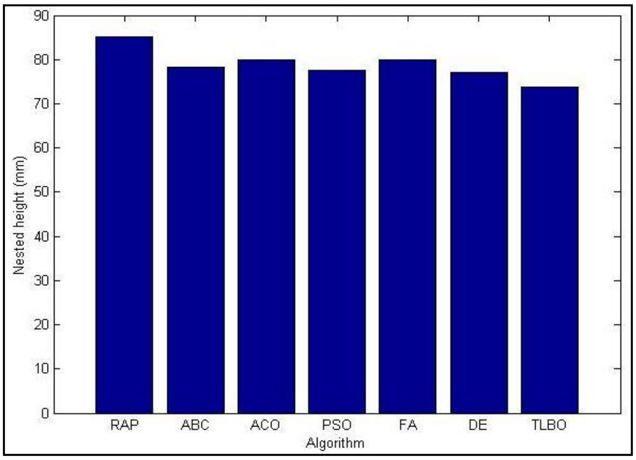


Figure 3. Comparison of nested heights for regular shaped parts

Table 2. Comparison of EUR and computational time for regular shaped parts

Problem	No. of parts	RAP	ABC	ACO	PSO	FA	DE	TLBO
EUR	22	0.799	0.833	0.814	0.839	0.816	0.846	0.888
Computational time (min)	22	-	8.21	7.54	7.98	7.25	8.01	6.43

Table 3. Comparison of EUR and computational time for irregular shaped parts

Problem	No. of parts	RAP	ABC	ACO	PSO	FA	DE	TLBO
EUR	22	0.708	0.730	0.750	0.715	0.795	0.779	0.807
Computational time (min)	22	-	12.54	11.67	11.41	11.87	11.52	10.48

Table 4. Paired t-tests for nested heights of regular and irregular shaped parts

Regular shaped parts					
Metaheuristics	ABC	ACO	PSO	FA	DE
t- value	-82.4	-101.3	-81.9	-290.7	-52.1
Irregular shaped parts					
Metaheuristics	ABC	ACO	PSO	FA	DE
t- value	-82.4	-101.3	-81.9	-290.7	-52.1

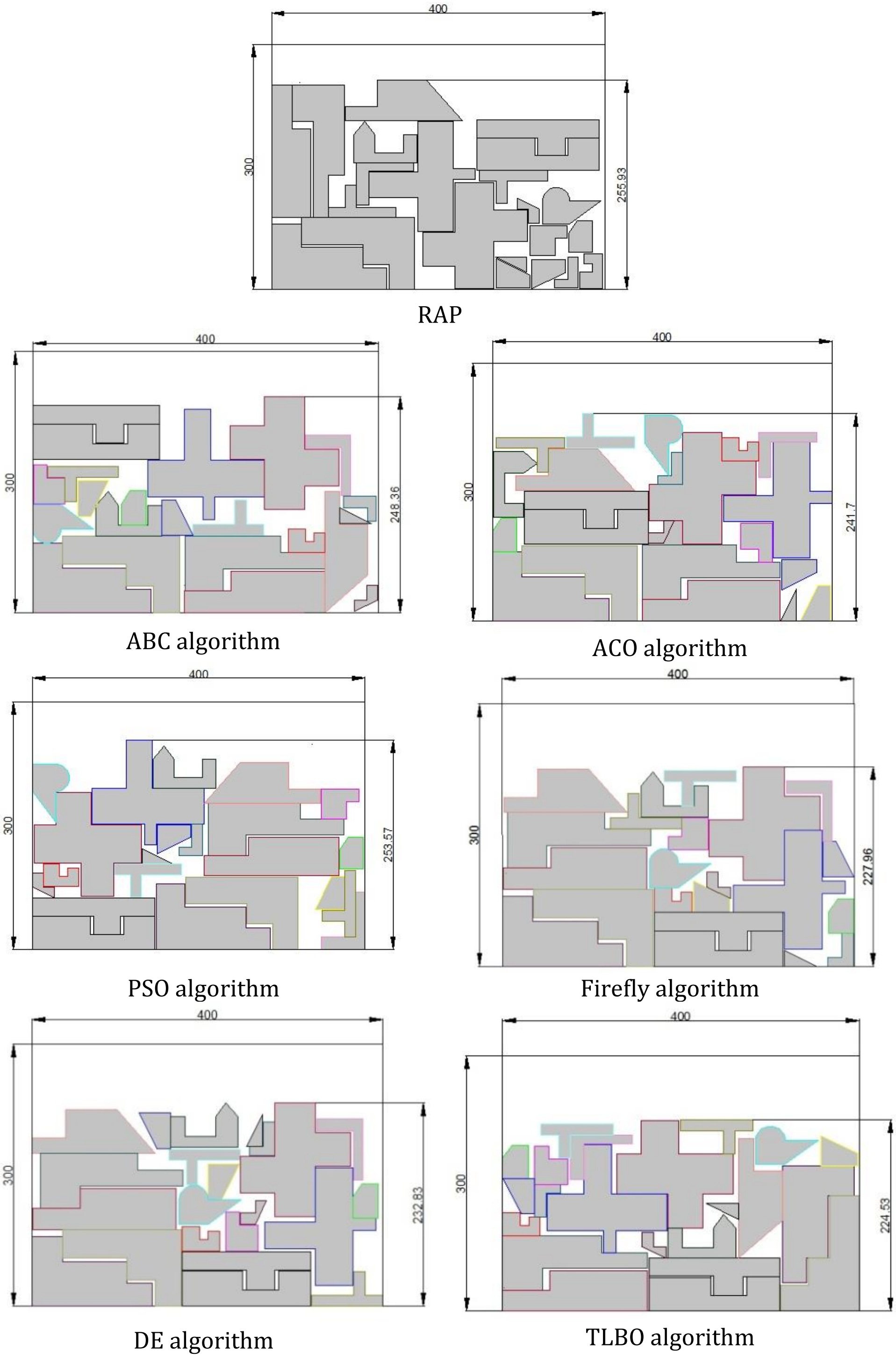


Figure 4. Optimal layouts for irregular shaped parts using different metaheuristics

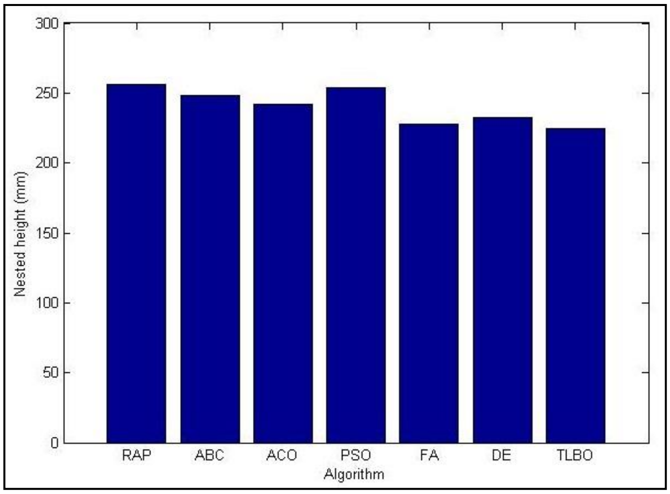
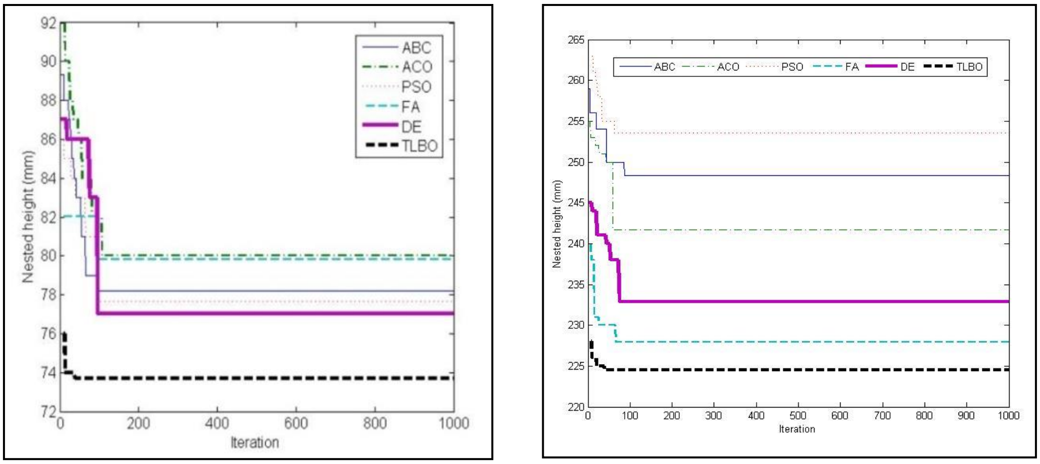


Figure 5. Comparison of nested heights for irregular shaped parts

The population mean denotes the average value of the objective functions calculated after 1000 iterations for each of the metaheuristics considered. The results of *t*-test are provided in Table 4 for both the problems. Based on these results, the null hypotheses for two-tailed *t*-test can be rejected because for all the paired comparisons between the considered metaheuristic algorithms, the absolute values of the test statistic are greater than the corresponding critical value at 5% level of significance. It thus proves the uniqueness of TLBO algorithm over the other algorithms under consideration. Thus, TLBO algorithm can be applied as an effective tool for determining the optimal nesting patterns for regular and irregular shaped objects with less computational effort.



(a) Regular (b) Irregular

Figure 6. Convergence diagrams for the considered metaheuristic algorithms

5. Conclusions

In this paper, six popular metaheuristic algorithms are applied to solve two-dimensional nesting problems for regular and irregular shaped parts based on BLF placement strategy during sheet metal cutting operation. The objective is set to reduce wastage of material by minimizing the nested height of two-dimensional parts resulting in reduction of the total area required for packing the parts in sheet metal. The solutions from the considered metaheuristic algorithms generate effective and optimal nesting patterns for different parts to be placed in the sheet metal before the actual cutting operation. It is observed that TLBO algorithm almost achieves the global optimal solution with minimum heights of the nested parts for both the considered problems. This algorithm also excels over the others with respect to EUR value and computational time. It achieves 6.60, 9.09, 5.84, 8.82 and 4.76% improvements on EUR, and 27.68, 17.26, 24.10, 12.75 and 24.57% reductions in computational time respectively against ABC, ACO, PSO, FA and DE algorithms for regular shaped objects. On the other hand, there are 10.55, 7.6, 12.87, 1.51 and 3.59% improvements in EUR, and 19.65, 11.35, 8.87, 13.26 and 9.92% reductions in the computational time in TLBO algorithm as compared to ABC, ACO, PSO, FA and DE techniques respectively for irregular shapes parts. Thus, it can be concluded that this algorithm can be successfully applied to determine the optimal patterns of parts to be positioned in a stock in metal cutting industries in order to minimize cutting time and trimming loss. The future scope of this paper may include determination of the optimal nesting patterns for parts with more complex configurations while applying other new metaheuristics, like BA, cuckoo search algorithm, grey wolf optimizer, Jaya algorithm etc. A comparative analysis between BLF algorithm and other heuristics, like rectangular placement method, quick location and movement (QLM), compact neighborhood algorithm (CLA) etc. for effective placement of objects in sheet metals may be another scope of this paper. The limitations of this paper include consideration of only BLF algorithm for placing two-dimensional objects in the sheet in non-overlapping patterns.

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