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Development of An Algorithm For Optimization of Nesting ProcessFor Allocation of Parts In Sheet MetalBy Particle Swarm Optimization (PSO)

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Abstract

An algorithm is developed for allocation problem by using Particle Swarm Optimization (PSO), which is a relatively new, modern, and powerful method of optimization that has been empirically shown to perform well on many of these optimization problems. It is widely used to find the global optimum solution in a complex search space. Certainfactors affecting the fitness functions of the algorithm are identified and an algorithmic approach is handled to find the changes in the solution. Also it is proposed to develop an algorithm using the above discussed fitness function by Particle Swarm Optimization in nesting the parts. The PSO program gives the optimal sequence and orientation of parts placed in the sheet which is of different dimensions. This work also discusses to check the variation in the optimality when one side optimization is taken for the analysis and this has been done by increasing the length of the sheet.

Keywords: Particle Swarm Optimization, Global Optimum Solution, Fitness function

Introduction

In today's competitive manufacturing environment, manufacturing industries are working hard to improve productivity, as well as reduce cost and lead-time. For industries such as the sheet metal industry, cloth industry, glass and ship building industry, their manufacturing operations often involve cutting new two-dimensional (2D) parts from batches of sheet materials. An important issue faced by these industries is how to find the optimum layout of 2D parts with different shape and size within the available sheet, such that the material utilization can be maximized and the resulting material wastage can be minimized. Nesting is a classic problem of finding the most efficient layout for cutting parts of a given sheet with minimum waste material. Manual methods are used to determine the arrangement of parts in some industries. Operators decide the layout from their experience, but this is not an efficient method because it is time consuming and the results do not efficiently utilize the raw material. It is challenging to obtain an efficient solution in a reasonable time when there are a large number of parts. Nesting is an hard problem and an optimal solution is impossible to calculate in a timely manner. Currently there is still lack of practical algorithms in industry to nest complex and multiplex parts [3]. But several researchers have attempted to develop methods for nesting rectangular shaped parts on rectangular sheets. Most of the nesting algorithms are limited to regular blank shapes such as rectangles or simple polygon shapes. When the blank shapes are irregular, initial conversion to approximate rectangular shapes are performed before the nesting process [6]. The nesting is characterized by the intrinsic difficulty of dealing with geometry, satisfaction of the no-overlapping and containment constraints and complex computation . It is reported that intelligent computer-aided nesting (CAN) system for optimal nesting of two – dimensional parts, especially parts with complicated shapes, with the objective of effectively improving the utilization ratio of sheet materials[12].It isproposed that typical nesting technique that is widely used is the geometrical tilting of single pattern or selected cluster step by step from the original position to an orientation of certain degrees [13]. This is a blind search of best stock layout and geometrically it becomesinefficient when several pattern entities are involved. **T**he detailed explanations of the most popular techniques for handling the geometry when solving nesting problems and provide guidance on their implementation, strengths and weaknesses. The techniques are raster method, direct trigonometry, No-fit polygon and phi functions Most of the research discuss on TYPE-II (Nesting of irregular parts in regular sheets) with the primary objective as on maximum material utilization.All the studies attempted to find the optimal layout of parts in the sheet metal but no study has been dealt with general optimal size reduction as objective which generally affects the utility factor.The primary focus of the thesis is to evolve optimal allocation in nesting process for the optimal material utilisation layout using PSO. However, this approach provides an initiative to consider simultaneously both the critical objectives of sheet metal cutting industries.

Particle Swarm Optimization

The Algorithm that is used for proceeding the project for allocation of parts in a sheet metal is PARTICLE SWARM OPTIMIZATION (PSO).

PSO Algorithm

Main idea: Mimic bird flocking or fish schooling

Table1: Table Comparing Nature With PSO

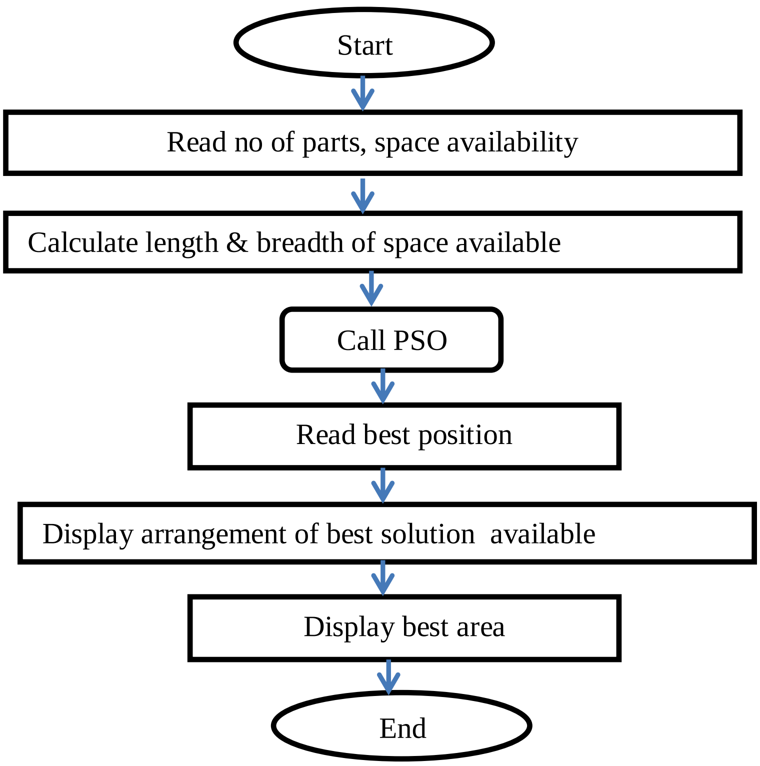
NATURE	***ALGORITHM***
Birds or fish	Particles
Explore the environment	Explore objective space(Nd) in search for good function values.
Exchange information by acoustical or optical means	Exchange information by sharing positions of promising locations

The PSO method is becoming very popular because of its simplicity of implementation as well as ability to swiftly converge to a good solution. It does not require any gradient information of the function to be optimized and uses only primitive mathematical operators

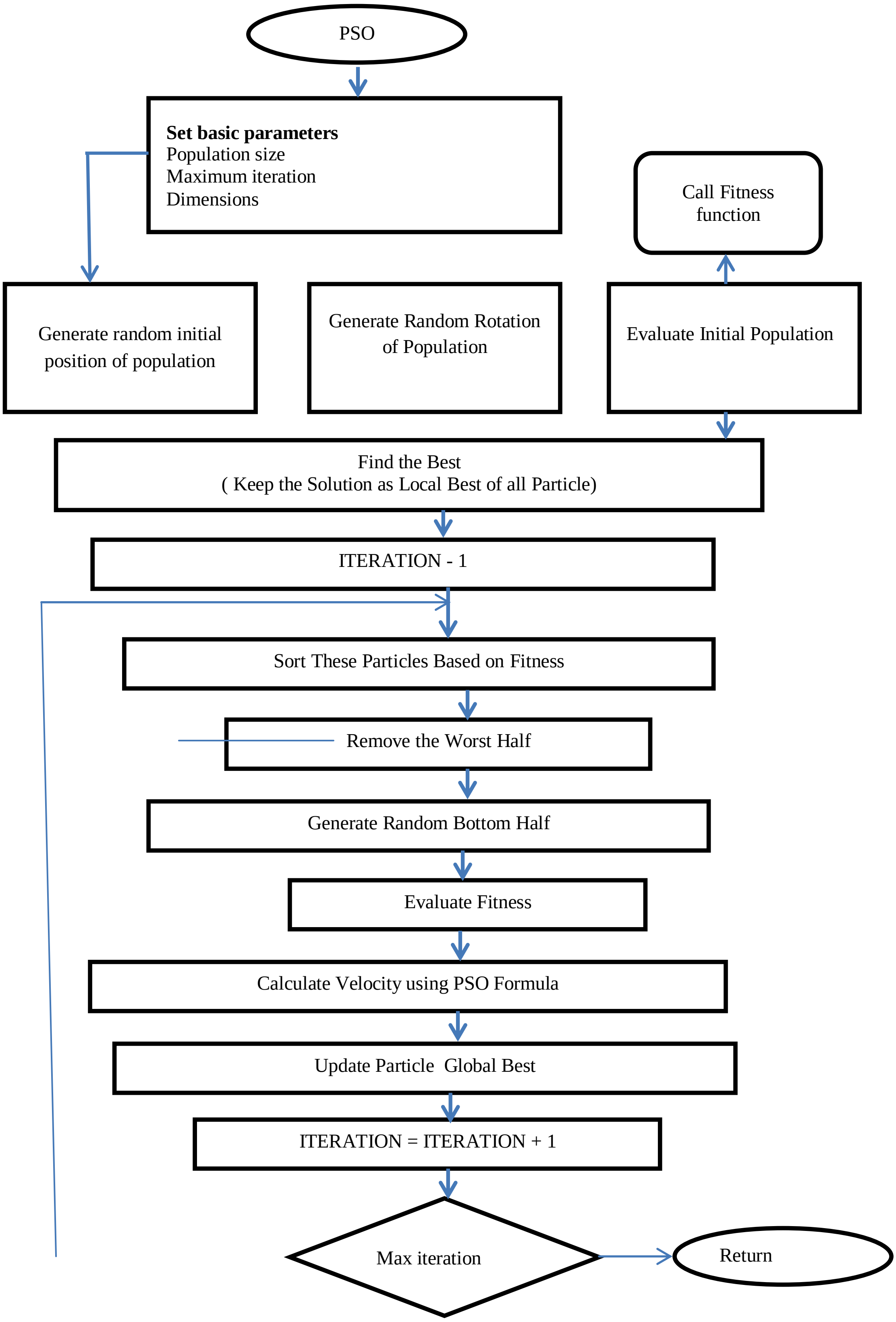
Details on The Analysis of The Algorithm
The program on MATLAB is explained clearly by the following flowcharts in which each steps follows its sub divisional programs that has been classified into three different flowcharts for understanding as follows:

1. Main Program
2. PSO Flowchart
3. Fitness Function

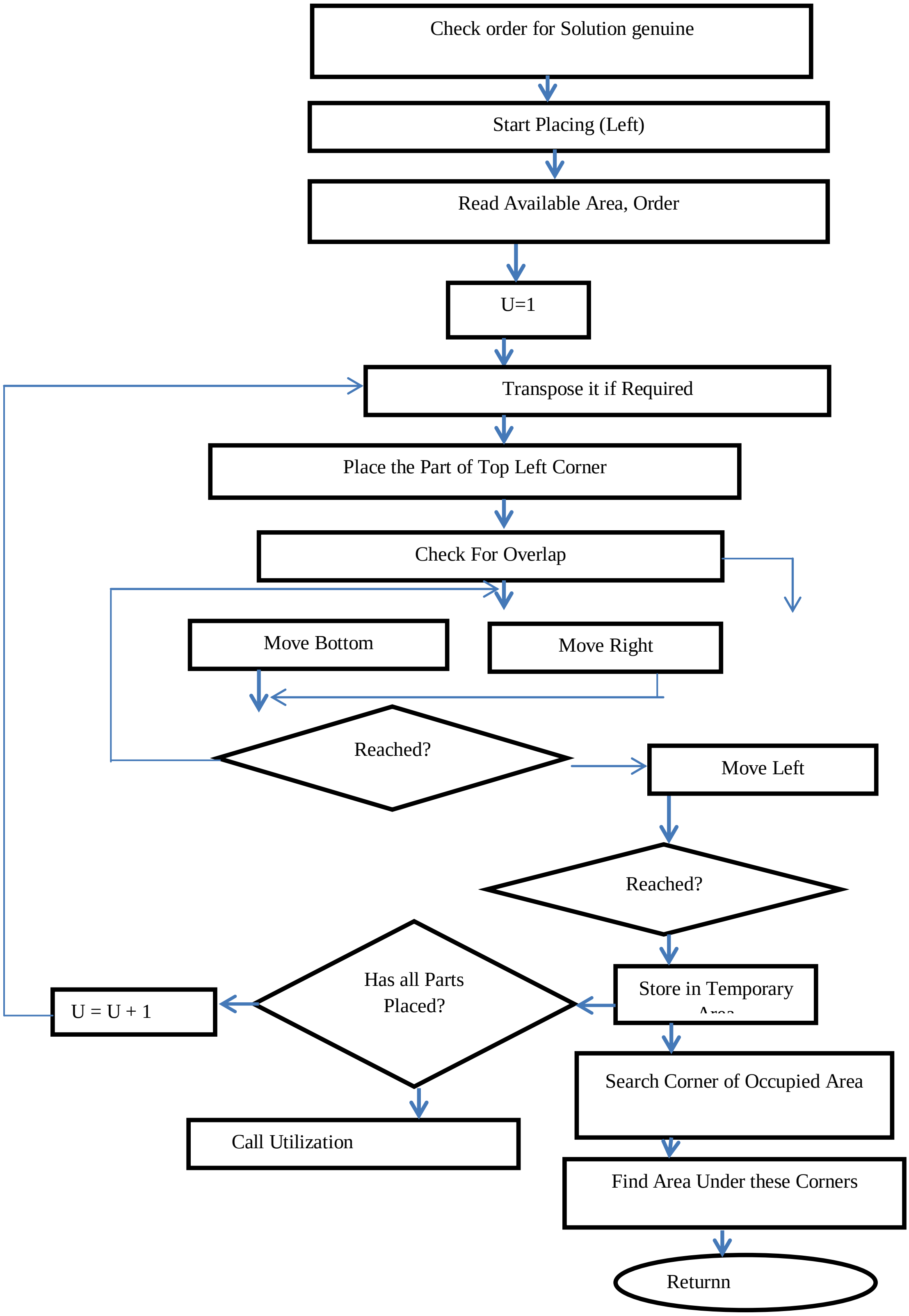
1. Main Program



2. PSO Flowchart



3. Fitness Function



Working of The Program:

For PSO method, the velocity of particle i is calculated by ,

$$v_{ij}^{t+1} = v_{ij}^{t} + c_1 r_{1j}^{t}[p_{best,i}^{t} - x_{ij}^{t}] + c_2 r_{2j}^{t}[G_{best} - x_{ij}^{t}]$$

where

v_{ij}^{t}- is the velocity of particle i in dimension j at time t

x_{ij}^{t}- is the position vector of particle i in dimension j at time t

$p_{best,i}^{t}$ - is thepersonal best position of particle i in dimension j found from initialization through time t

G_{best} - is the global best position of particle i in dimension j found from initialization throughtime t

C1 and C2 are positive acceleration constants which are used to level the contribution of the cognitive and social components respectively.

$r_{1j}^{t} and r_{2j}^{t}$are random numbers from uniform distribution u(0,t) at time t.

In proposed work, each solution which is referred as an individual particle in PSO is a 2n dimensional vector where n represents the number of parts to be placed. In the formulation of the algorithm this 2n dimensional vector is considered as a composition of two individual n dimensional vectors with the first vector represents the order in which the parts are taken up for optimization and the second vector represents the orientation with which the parts are placed.

The n dimensional vector associated with the representation of orientation of arts is primarily considered as to have only either 0's or 1's. The bit 0 represents that the part has been considered for placement without any change in orientation whereas a digit of 1 will represent that the part has been rotated by an angle of 180^{o}.

During the operation of velocity calculation, which is required for the movement of particle from one position to another in the search space, only the n dimensional vector representing the orientation of the object is modified. Thus it may be summarily concluded that as the algorithm progresses, it tries to find the best n-dimensional orientation vector that results in reduced allocation area for a given n-dimensional order of arrangement. In order to avoid the stagnation of mediocre solution an additional feature is added in the algorithm which is similar to the selection process employed in GA. By this, at the end of every iteration, the particles are sorted based on their fitness and the bottom half of the solutions which are comparatively ineffective are removed and random new particles are generated instead of them. Thus at the end of each iteration, the total population of the swarm is maintained constant.

Consider a problem of placing 5 parts, thus each solution becomes a 10 dimensional vector as shown in the figure.

2	5	4	1	3	0	1	1	0	1

For velocity calculation, the above vector may be compared to another solution which represents the same sequence of parts in further iteration which is done as shown below.

Stage 1:

P1

2	5	4	1	3	0	1	1	0	1

P2

2	5	4	1	3	1	1	0	0	1

Stage2:
P1- P2

2	5	4	1	3	-1	0	1	0	0

Stage 3:
C_1rand(P1-P2)

2	5	4	1	3	-0.4	0	0.4	0	0

2	5	4	1	3	0	0	1	0	0

Consider two vectors P1 and P2 shown above. According to the velocity calculation formula of PSO, both the vectors are first subtracted. As stated earlier all operation on the solution is done only on the n-dimensional vector which represents the orientation whereas the n-dimensional vector representing the sequence remains untouched. After necessary arithmetic manipulations as shown in stage 2, a vector similar to the one represented in stage 3 is obtained. Here it can be noticed that the n-dimensional vector representing the orientation is not of binary in nature but has become real numbered. Hence a switching logic as shown below is applied to convert the real numbered part into binary part.

$x_{ib} = \{ 1 \quad x_{ir} > 0$
$\{ 0 \quad x_{ir} <= 0$

Where x_{ib}represents elements in binary numbered n-dimensional orientation array and x_{ir} represents elements in real numbered n-dimensional orientation array.
Thus a new vector is formed using the PSO formula.

Utility Factor

To compare the effectiveness of various methods and the efficieny of their allocation, the Utility Factor can be used as a performance measure. Utility Factor can be defined as the ratio of Sum of Effective Area of All the parts to the Total Rectangular Allocated Area allocated by the method.

Results and Discussions

Test Problem taken:

Problem:

Number of rectangles: 16
Part 1 : 2 X 12
Part 2 : 7 X 12
Part 3 : 8 X 6
Part 4 : 3 X 6
Part 5 : 3 X 5
Part 6 : 5 X 5
Part 7 : 3 X 12
Part 8 : 3 X 7
Part 9 : 5 X 7
Part 10: 2 X 6
Part 11: 3 X 2
Part 12 : 4 X 2
Part 13 : 3 X 4
Part 14 : 4 X 4
Part 15 : 9 X 2
Part 16 : 11 X 2

(The following instances of a 2D rectangular *packing problem have been used in the paper entitled "An Empirical Investigation of Meta-heuristic and Heuristic Algorithms for a 2D Packing Problem" that has been accepted for publication by the European Journal of Operations Research in June 99.)*

Sum of All Parts Area:

(2*12) + (7*12) + (8*6) + (3 * 6) + (3*5) + (5*5) + (3*12) + (3*7) + (5*7) + (2*6) + (3*2) + (4*2) + (3*4) + (4*4) + (9*2) + (11*2) = 400.

Result 1:

Sheet Dimension : 40 x 40.

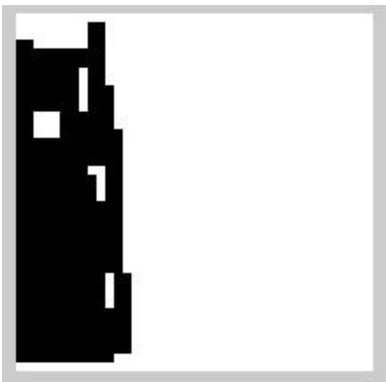


Figure 1:MATLAB Result For Sheet Dimension 40x40

The Best ordering mechanism is

PART NO.	ORIENTATION
3	1
2	1
9	1
16	0
4	1
7	1
13	0
8	1
6	1
10	0
15	0
1	1
14	0
5	1
11	0
12	0

Resulting in a allocation area = 438
The Dimensions of the resultant packing is
38 x 13

Result 2:
Sheet Dimension : 50 x 40.

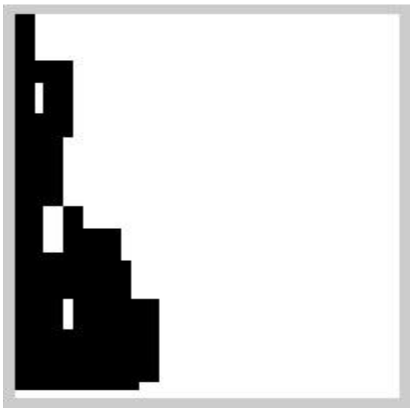


Figure 2: MATLAB Result for sheet Dimension 50x40

The Best ordering mechanism is

PART NO.	ORIENTATION
3	0
9	1
5	0
4	1
7	1
11	0
12	0
10	1
2	1
1	1
15	0
8	1
13	0
16	0
6	1
14	0

Resulting in a allocation area = 446
The Dimensions of the resultant packing is 49 x 12

Result 3:
Sheet Dimension: 60 x40

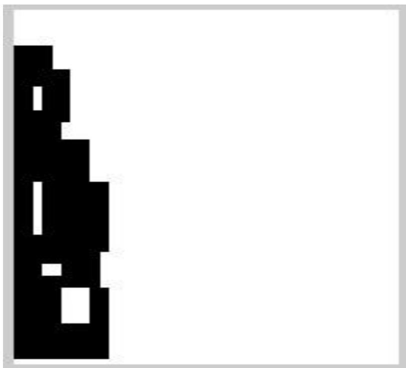


Figure 3: MATLAB Result for sheet Dimension 60x40

The Best ordering mechanism is

PART NO.	ORIENTATION
3	1
6	1
5	0
8	1

15	0
7	1
16	0
1	1
14	1
10	0
2	1
9	1
11	0
4	1
13	0
12	0

Resulting in a allocation area = 454
The Dimensions of the resultant packing is 53 x 10

Result 4:
Sheet Dimension: 70x40

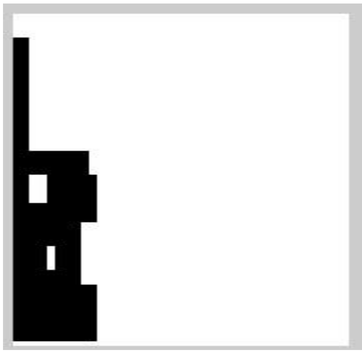


Figure 4:MATLAB Result For Sheet Dimension 70x40The Best Ordering Mechanism Is

PART NO.	ORIENTATION
2	1
5	0
12	1
13	0
6	1
14	0
15	0
16	0
11	0
1	1
7	1

4	1
8	1
10	0
3	0
9	0

Resulting in a allocation area = 456
The Dimensions of the resultant packing is
64 x 9
The Results of Area Allocated and Utility Factor for Different Sheet Dimensions are mentioned in Table.2.

Table2: Results of Area Allocated and Utility Factor for Different Sheet Dimensions

SHEET DIMENSION	ALLOCATED DIMENSION	AREA ALLOCATED	UTILITY FACTOR.
40X40	**38X13**	**438**	**0.913**
50X40	**49X12**	**446**	**0.896**
60X40	**53X10**	**454**	**0.881**
70X40	**64X9**	**456**	**0.877**

Chart 1

Breadth Vs Length.

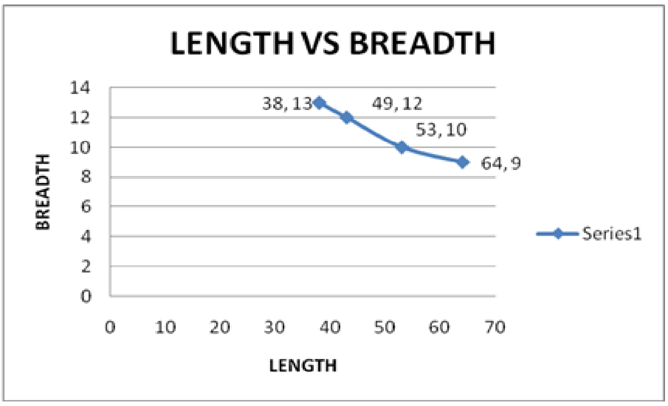


Figure 5: Chart Showing the Variation on Length VS Breadth.

Chart 2
Length Vs Utility Factor

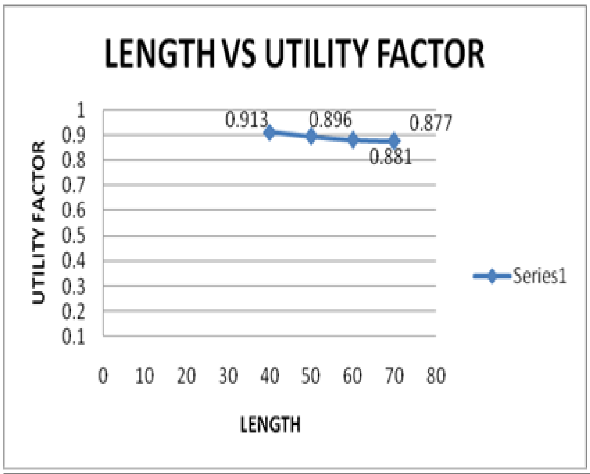


Figure 6: Chart Showing the Variation on Length VS Utility Factor.

Conclusion

The PSO program gives the optimal sequence and orientation of parts placed in the sheet which is of different dimensions. To check the variation in the optimality when one side optimization is taken for the analysis and this has been done by increasing the length of the sheet.

The test results have been compiled as a graph as shown in the figure. The first figure shows the optimization process done when the length of the sheet is changed. It can be seen that as the length of the sheet increases the corresponding breadth decreases. This is in accordance with the expected result.

The project was focused on developing the PSO application for the sheet metal cutting application. For sheet metal application, the general optimal size reduction objectives found in the literary papers were modified to effectively function as reduction in breadth of the area required such that the area is also minimized.

1) Graph 1 shows that, when the length of the sheet metal was increased, the PSO program functioned effectively to as to reduce the breadth of the required sheet.
2) Graph 2 can be used to indicate the fact that, in the process of reducing the breadth of the required sheet, the program does not fail in effectively reducing the total area required. It can be seen that an almost constant utilization factor is achieved for various lengths, indicating the effectiveness of the program.

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