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Optimization of workpiece location and tool path movement on CNC machining center using Genetic algorithm

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Abstract

Due to the high running cost of CNC machines so the most studies are based on optimization of resident time of CNC by using such an optimization method according to the huge number of approached points in different machining features especially in multi components case.

Most research in this area has concentrated on optimization of rapid movements (air time motion) and machining movements of drilling, pocketing, and face milling operations. Minimizing the machining time during chip generation by optimizing the cutting parameters, the tool sequence and the tool pathsto be used during cutting were studied by many researchers.

However, the optimization of components location is not presented till now in spite of its effect on tool travel as well as machining cost.

In this study, a methodology is developed to find the optimum location of a work-piece on the long table of a CNC milling machine which leads to minimum X, Y and Z axes movement between manufacturing features on different components. The near optimum location of the workpiece is set corresponding to the minimum movement of different axes and number of tool changes of the milling machine. A new methodology is used in this study using Genetic algorithm (GA) and Rank Order techniques to determine the near optimum location of the work-piece. (This save the energy consumption and improve the resident time) significantly.

Keywords: CNC milling machine Workpiece location Optimization GA Rank Order

1. INTRODUCTION

Vertical and horizontal machining centers are now used in a wide range of industries ranging from made to order companies where complex one-off jobs are the norm, to multi-component manufacturing companies where many smaller components are manufactured. Machining center utilization is not optimal. This is because in the one-off situation there is a tradeoffbetween the time spent in the hand preparation of the part program, and the time spent in machining. Thelatter often results in non-optimal machining center use; and, in the multi component situation, where a pallet (or long machine tables) is composed of up to thirty different components andrequires a tool magazine of over huge tools, the machine tool use is non-optimal for a number of reasons [1]. Typical factors which influence the optimally of use are: the location of component on the machine table or on the pallet, the sequence in which the tool are selected, and either the order in which the individual component part programs are called or the manner in which the multi –component part program is hand written for the entire pallet. These factors all influence the residence time and in particular the non-machining time (e.g., tool changes, pallet rotation, movements between different components and machining contours).

There has been much significant research interest optimization. Most research in this area has concentrated on productive time, non-productive time, cutting conditions, optimization of tool sequencepacking, .etc. **Xiaorui Chen** presented a new methodology to offset multiplepolygonswith arbitrary holes, where overlapping is prevented.[2]**P Selvaraj** presented an algorithm to minimize the tool path for pocket-milling using zig-zag method.[3]**ZHIYANG YAOy** presented a methodology to generate a tool path by in different regions of the geometry using different patterns [4]. **CuneytOysu**developed an optimization technique to minimize the non-productive time using a hybrid algorithm (GA/SA)[5].**Doriana**developedan optimization technique based on genetic algorithms (GA) to optimize the cutting parameters in manufacturing[6]. **Adnan Jameel**presented a review of the near optimum cutting parameters and its variants in turning using Genetic algorithm[7]. **Ali Oral**proposed an optimization technique of tool sequences to be used for turning in process planning system[8].**GjelajAfrim**developed an optimization technique for tool selection using a genetic algorithm[9].**E. Hopper**developed an optimization algorithm using hybrid technique used for optimizing the packing of rectangular parts [10]. **Mao Chen**developed an optimization technique to solve packing problem used in two dimensional rectangular parts[11]. **HaraldDyckhoff**developed a new approach used for trimming and packing problems[12]. **M. ZahidGürbüz**presented an algorithm technique for optimizing the 3D packing problem[13]. **Nian-ZeHu**presented a new methodology to solve and optimize a packing optimization problem. The developed techniqueconverts the nonlinear objective function (of the original packing problem) into a linear function with the given parameters[14].**Anand**presented a two-dimensional nesting optimization methedology suitable for a sheet metal industries employing profile blanking laser cutting and processes[15].

This research is focused on developing the methodologies required to optimize the non-productive tool movements on a long machine table or on a pallet faces of multi-component, multi-tool and multi axis machines using generic computer –based techniques to allocate the components on the available area on the machine table or pallet using a new methodology combined of **Rank order** technique and **Genetic optimization** technique, while taking into account the non-productive tool movement between the contours on the different components which will result in the reduction of non-machining time.

The reduction of non-machining time leads to total residence time reduction as well as machining cost.

The Rank order Clustering technique which is mainly deals with clustering of parts into part families, and the machines into machine cells. Parts are grouped into part families based on similarities in their manufacturing and design attributes and the machines are allocated into machine cells to produce the identified part families. Zero-one part machine incidence matrix is commonly used as input to any clustering algorithm. Output is generated in the form of block diagonal structure.

Many optimization techniques can be used to solve this problem, such as simulated genetic algorithm, annealing algorithm, ant-colony algorithm, neural network algorithm and genetic algorithm which be used to solve such a problem.

A Genetic algorithm is a probabilistic search method that transforms a set of mathematical objects into a new set of objects. The set is called population, each object within the set have a fitness value. The objects

Are usually fixed length binary character strings. New set is the new population contains some individuals from previous set added to it population of offspring based on Darwinian's principle of natural selection and using operations such as crossover and mutation.

Genetic algorithm search process includes survival of the fittest principle applied by selecting the individuals that adapt well to their environment which are the constraints. In other words, over the iterations which are the generations, individuals or the possible solutions that have characteristics required will remain within the

Next generation instead of those with less desired characteristics. Selection of individuals is done stochastically depending on their fitness function.Crossover in GA complexity is according to wither an array have variable or fixed length.

This paper proposes a new method for solving workpiece allocation optimization problems based on Rank order technique and Genetic algorithm.

This problem has been solved by defining the available area on machine table or pallet, the dimension of each component, and the position of each contour relative to its component origin, which will seek the minimization of non-productive tool movement.

2. PROBLEM FORMULATION

The proposed algorithm is implemented on Matlab software. The input is a text file that will be imported from a module of integrated developed software where each line represents a workpiece with its parameters (length, width, and fixture allowances) and the tools used for each workpiece, the whole file can be considered as initial solution of workpieces positions (represents one chromosome).

The workpiece allocation optimization is seek to optimize the total residence time by minimizing the number of tool changes.

The developed software minimize the number of tool changes by approaching the workpieces which used the same tools beside each other's.

Approaching the workpieces which used the same tools beside each other's leads to minimization of tool path of each tool then minimization of non-productive time.

This step is done by an idea taken from Rank order technique (with some changes) by calculating a factor which we named it as Totals Weight factor (T.W.F.).

Where, T.W.F. is a summation of all weight factors of each used tool.

Weight factors of each tool can be calculated using the following equation

Weight factor of tool j $= \sum_{p=1}^{n} b_{pj} 2^{m}$ equation 1

Where n is the number of workpieces

$$m = \begin{cases} 1 \text{ if } p = 1 \\ m+1 \quad \text{if } b_{p-1} = 1 \\ 1 \quad \text{if } b_{p-1} = 0 \end{cases}$$ equation 2

Where $b$is binary number equal to zero if workpiece does not use such a tool and equal to 1 if workpiece uses the tool.

As, shown in the following example

Workpiece ID	T_1	T_2	T_3	T_4
4	0	0	1	1
3	0	0	1	1
6	0	1	0	0
5	0	1	0	1
2	1	1	0	0
1	1	1	0	0

Table 1
Weight factor calculation

Weight factor of $T_1 = 0+0+0+0+2^1+2^2=6$

Weight factor of $T_2 = 0+0+2^1+2^2+2^3+2^4=30$

Weight factor of $T_3 =2^1+2^2+0+0+0+0=6$

Weight factor of $T_4 =2^1+2^2+0+2^1+0+0=8$

T.W.F. = 6+30+6+8=50

The workpiece allocation optimization problem is stated as follows:

Maximize T.W.F.(Total weight factor)

Subject to

1. All of n workpieces are non-overlapping.
2. Workpiece orientation are allowed to fit the available area of machine table (or pallet).

3. THE DEVELOPED METHEDOLOGY STEPS

The developed technique used in this paper will be explained through using a case study consists of 6 workpieces as follows (see table2).

Step 1: After having the initial solution which is given from the imported text file (one chromosome), a random population can be initialized by constructing 100 chromosomes based on that chromosome.

Step 2: calculate an integer weight factor for each tool (column) using equation 1 and equation 2, and then calculate the total weight factor of all 100 random solutions (initial population) (see table1).

Step 3: (Parents selection) Selection is done using two methods elitism and random method. In elitism the best individuals are selected for a crossover, it can be done easily since the population is already sorted. Random method (which is used in this developed software): two indices are randomly picked, the solutions(chromosomes) at these indices will be the parents.

workpiece ID	WpLength mm	WpWidth mm	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Clamping allowances In X	Clamping allowances In Y
6	80	150	0	1	0	1	1	1	1	30	30
1	100	100	1	1	0	0	0	0	0	10	10
4	160	60	0	0	1	1	1	1	0	20	20
2	100	100	1	1	0	0	0	0	0	10	10
3	160	60	0	0	1	1	1	1	0	20	20
5	80	150	0	1	0	1	1	1	1	30	30
W.F.			4	10	4	10	10	10	4		

Total Weight Factor = 4+10+4+10+10+10+4+0+0+0 = 52

Table 2
Calculating T.W.F

Step 4: (Crossover) after selecting the two random solutions (two parents), apply a crossover using order 1 crossover (figure 1):

- Choose a random segment from first solution (first parent).
- Place the segment in the new solution(offspring).
- Copy the second solution (second parent) points that doesn't appear in the segment in the same arrangement.

Parents

Piece1	Piece2	Piece3	Piece4	Piece5	Piece6

Piece6	Piece5	Piece4	Piece3	Piece2	Piece1

Child

			Piece4	Piece5	

Piece6	Piece2	Piece3	Piece4	Piece5	Piece1

Figure 1
Crossover

Step 5: (Mutation) after a crossover, apply mutation to the offspring using scramble mutation (figure 2).

- Choose a segment from the offspring.
- Rearrange the workpieces (genes) randomly within this segment.

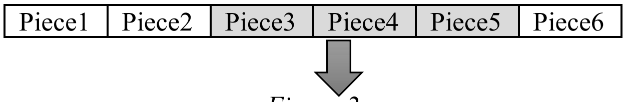


Figure 2
Mutation

Step 6: (Insert Children) Offspring are added to current population and sorted according to fitness value, the solution(chromosomes) with the least T.W.F.(fitness value) are deleted from the population. Also any individuals that are repeated are deleted from the population. This guarantee the best individuals survive to next population. This is called survivor selection where the individuals to next population are selected. The chosen method selected is fitness-based or proportionate selection – Genitor: which is deleting the worst individuals leads to rapid improvement. Stopping criteria is reaching a certain number of iterations.

Step 7: Getting the near optimum allocation of the givenworkpieces as shown in a table (3)

ID	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
4	0	0	1	1	1	1	0	0	0	0
3	0	0	1	1	1	1	0	0	0	0
6	0	1	0	1	1	1	1	0	0	0
5	0	1	0	1	1	1	1	0	0	0
2	1	1	0	0	0	0	0	0	0	0
1	1	1	0	0	0	0	0	0	0	0
Total Weight Factor = 146										

Table 3
Near optimum solution

Step 8: Adding fixture allowances to each workpiece, and then arranged them sequentially.

Step 9: The first workpiece in the sequence is positioned on the bottom left corner of machine table (pallet face) as shown in Figure 3, and the nodes suitable to place the next part are identified by projectingtop-left corner of the workpiece.

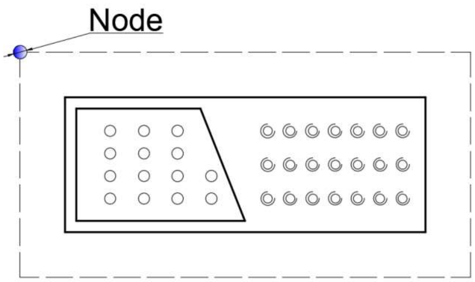


Figure 3

Step 10: The next part in the sequence, is positioned at the new node. And the newer nodes are generated again to place the subsequent parts.

Step 11: repeating step10; however, the condition of rest table width is less than workpiece width + allowance is valid. If, this condition is not valid the developed software will try to rotate the workpiece 90 degree and check if the rest table width is greater than workpiece length + allowance or a new column will be started from the upper left corner node. As shown in (Figure 5(a), 5(b), and 5(c)).

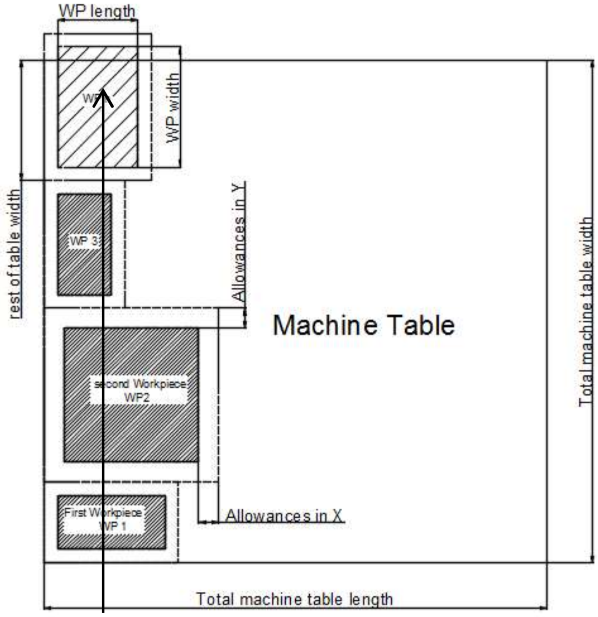


Figure 5(a)

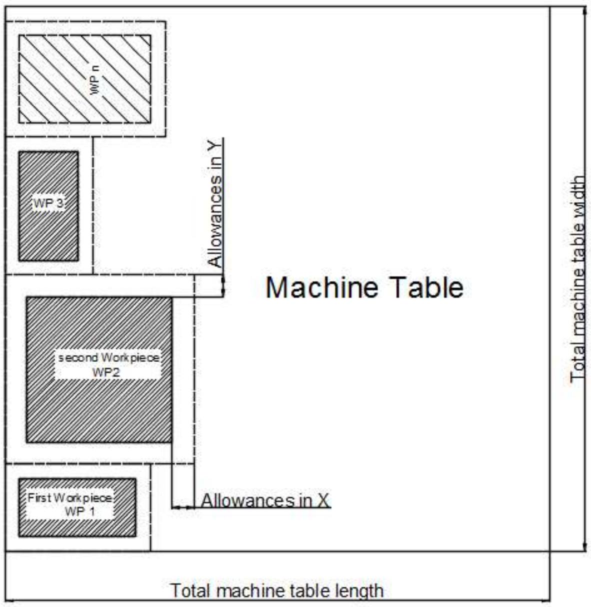


Figure 5(b)

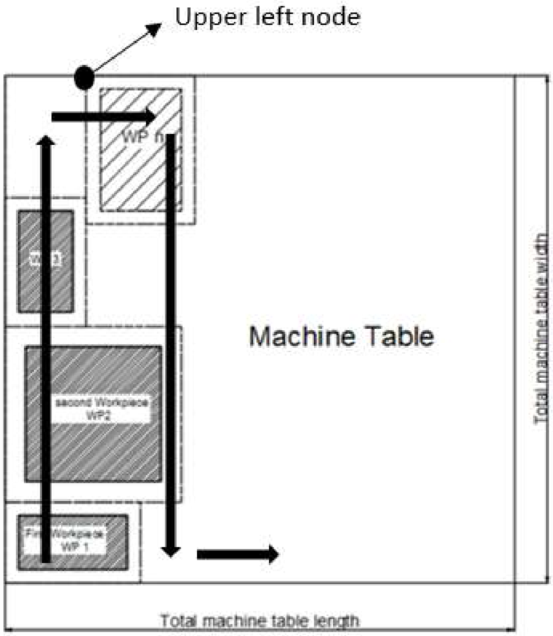


Figure 5(c)

Step 12: Complete in the same way till locate all workpieces

Step 13: Getting the new reference point (program zero) of each workpiece depending on user defined machine table dimensions (in this example machine table dimensions is 750X1000 mm) and taking fixture allowances, and the ability of orientation (if needed) into consideration.

Step 14: applying the previous technique on the initial workpiece allocation (initial population) and near optimum solution and get the program zero (X and Y coordinates) and orientation (take the value 1 if the workpiece is rotated 90 degree to fit the rest space of the machine table) of each workpiece as shown in tables (3, 4).

Workpiece ID	X coordinate of program zero	Y coordinate of program zero	Orientation
6	30	30	0
1	10	220	0
4	20	350	0
2	10	440	0
3	20	570	0
5	230	570	0

Table 4
Program zero of initial solution workpieces

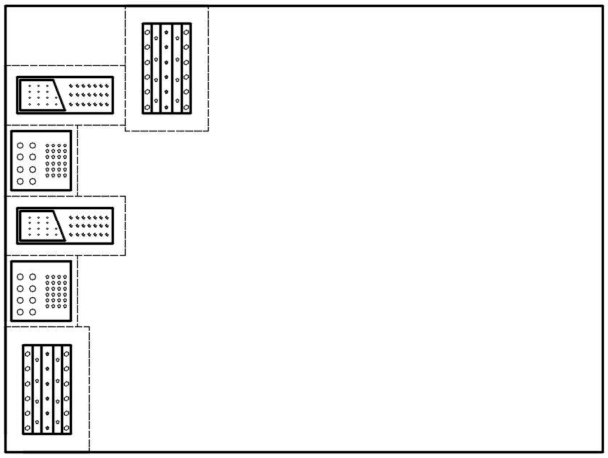
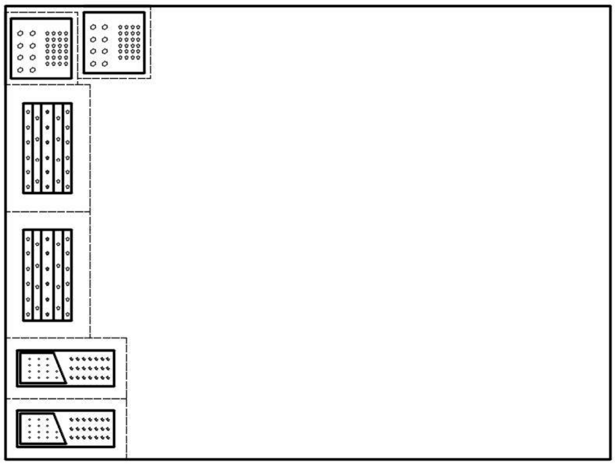


Figure 6
Workpiece allocation of initial solution

Workpiece ID	X coordinate of program zero	Y coordinate of program zero	Orientation
4	20	20	0
3	20	120	0
6	30	230	0
5	30	440	0
2	10	630	0
1	130	640	0

Table 5
Program zero of near optimum solution workpieces

Using such a non-productive time optimization module (using Genetic algorithm) for the initial population allocation and near optimum solution allocation we get



Initial time = 2462.2 sec

Initial distance = 219530 mm

Final time = 625.6891 sec

Final distance = 74211 mm

Number of Tool Change= 9

Optimization = 74.5882 %

After applying the optimization of workpiece allocation technique the results will be as follows:

Final time= **473.7941** sec

Final distance =**54724**mm

Number of Tool Change = **8**

Optimization =**80.7573 %**

4. CASE STUDY

Initial population of 22 workpieces allocation

Workpiece ID	L	W	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Allowances In X	Allowances In Y
17	**80**	**150**	0	1	0	1	1	1	1	30	30
1	**100**	**100**	1	1	0	0	0	0	0	10	10
19	**80**	**150**	0	1	0	1	1	1	1	30	30
13	**160**	**60**	0	0	1	1	1	1	0	20	20
2	**100**	**100**	1	1	0	0	0	0	0	10	10
10	**160**	**60**	0	0	1	1	1	1	0	20	20
15	**160**	**60**	0	0	1	1	1	1	0	20	20
18	**80**	**150**	0	1	0	1	1	1	1	30	30
8	**100**	**100**	1	1	0	0	0	0	0	10	10
9	**160**	**60**	0	0	1	1	1	1	0	20	20
20	**80**	**150**	0	1	0	1	1	1	1	30	30
5	**100**	**100**	1	1	0	0	0	0	0	10	10
11	**160**	**60**	0	0	1	1	1	1	0	20	20
22	**80**	**150**	0	1	0	1	1	1	1	30	30
6	**100**	**100**	1	1	0	0	0	0	0	10	10
12	**160**	**60**	0	0	1	1	1	1	0	20	20
4	**100**	**100**	1	1	0	0	0	0	0	10	10
3	**100**	**100**	1	1	0	0	0	0	0	10	10
16	**80**	**150**	0	1	0	1	1	1	1	30	30
14	**160**	**60**	0	0	1	1	1	1	0	20	20
21	**80**	**150**	0	1	0	1	1	1	1	30	30
7	**100**	**100**	1	1	0	0	0	0	0	10	10

Program zero of each workpiece of initial population

Workpiece ID	X coordinate of program zero	Y coordinate of program zero	Orientation
17	30	30	0
1	10	220	0
19	30	410	0
13	20	610	0
2	210	640	0
10	220	530	0
15	160	430	0
18	170	230	0
8	150	90	0
9	160	20	0
20	370	30	0
5	290	220	0
11	300	350	0
22	430	460	0
6	550	640	0
12	560	550	0
4	550	420	0
3	490	300	0
16	510	110	0
14	640	20	0
21	650	130	0
7	670	320	0

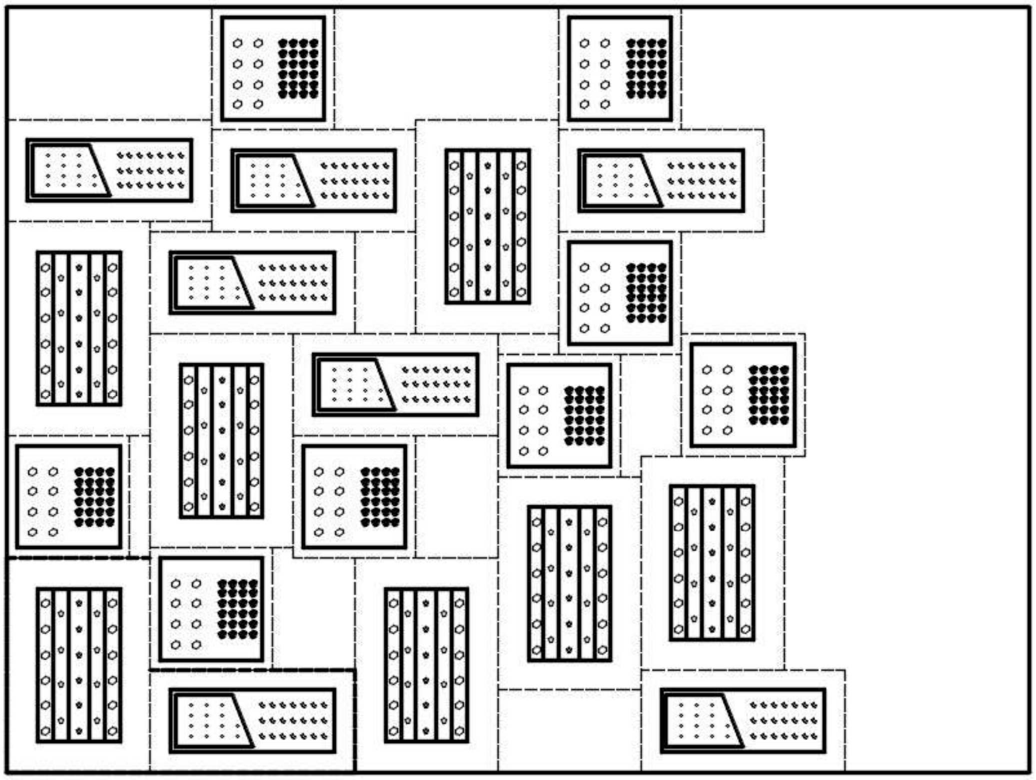
Near optimum solution

Workpiece ID	L	W	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Allowances In X	Allowances In Y
6	**100**	**100**	1	1	0	0	0	0	0	0	0	0	10	10
9	**160**	**60**	0	0	1	1	1	1	0	0	0	0	20	20
15	**160**	**60**	0	0	1	1	1	1	0	0	0	0	20	20
10	**160**	**60**	0	0	1	1	1	1	0	0	0	0	20	20
11	**160**	**60**	0	0	1	1	1	1	0	0	0	0	20	20
13	**160**	**60**	0	0	1	1	1	1	0	0	0	0	20	20
12	**160**	**60**	0	0	1	1	1	1	0	0	0	0	20	20
14	**160**	**60**	0	0	1	1	1	1	0	0	0	0	20	20
20	**80**	**150**	0	1	0	1	1	1	1	0	0	0	30	30
19	**80**	**150**	0	1	0	1	1	1	1	0	0	0	30	30
18	**80**	**150**	0	1	0	1	1	1	1	0	0	0	30	30
22	**80**	**150**	0	1	0	1	1	1	1	0	0	0	30	30
16	**80**	**150**	0	1	0	1	1	1	1	0	0	0	30	30
17	**80**	**150**	0	1	0	1	1	1	1	0	0	0	30	30
21	**80**	**150**	0	1	0	1	1	1	1	0	0	0	30	30
4	**100**	**100**	1	1	0	0	0	0	0	0	0	0	10	10
1	**100**	**100**	1	1	0	0	0	0	0	0	0	0	10	10
7	**100**	**100**	1	1	0	0	0	0	0	0	0	0	10	10
5	**100**	**100**	1	1	0	0	0	0	0	0	0	0	10	10
8	**100**	**100**	1	1	0	0	0	0	0	0	0	0	10	10
3	**100**	**100**	1	1	0	0	0	0	0	0	0	0	10	10
2	**100**	**100**	1	1	0	0	0	0	0	0	0	0	10	10

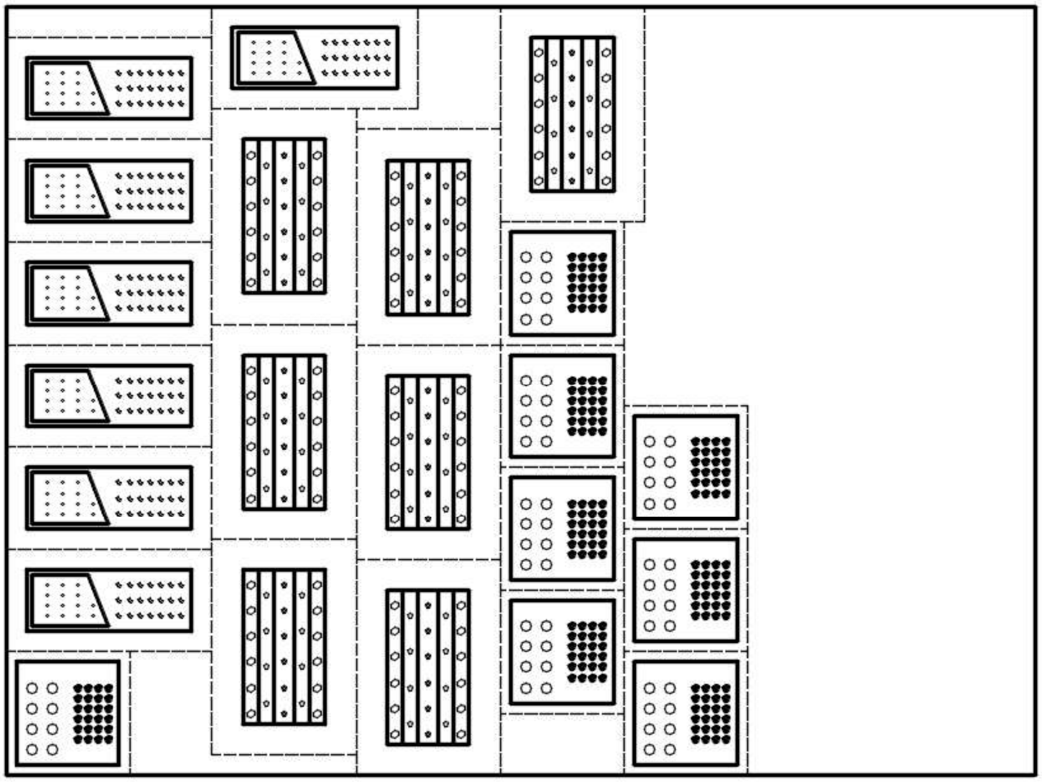
Program zero of near optimum solution

Workpiece ID	X coordinate of program zero	Y coordinate of program zero	Orientation
6	10	10	0
9	20	140	0
15	20	240	0
10	20	340	0
11	20	440	0
13	20	540	0
12	20	640	0
14	220	670	0
20	230	470	0
19	230	260	0
18	230	50	0
22	370	30	0
16	370	240	0
17	370	450	0
21	510	570	0
4	490	430	0
1	490	310	0
7	490	190	0
5	490	70	0
8	610	10	0
3	610	130	0
2	610	250	0

Allocation of initial population



Allocation of near optimum solution



Initial time = 9135.3 sec

Initial distance = 863000 mm

Final time= 3310.5 sec

Final distance = 409320mm

Number of Tool Change =9

Optimization = 63.7611 %

After applying optimization of workpiece allocation technique

Final time = **1986** sec

Final distance= **276620** mm

Number of Tool Change = **8**

Optimization= **78.75 %**

5. CONCLUSION

In this study, an optimization method is proposed to determine the best location of the work-pieces according to the common used tools and taking the fixture allowances and no overlapping between workpieces into consideration to minimization the resident machining time. GA technique is used to determine the optimum location of the workpiece origin using such a technique like rank order technique. However, the workpiece's origin is determined by another module starting with a first workpiece which is put in the lower left corner of the machine table and get the new node and so on. After, applying optimization of the non-productive time for the initial and near optimum location it is found that the near optimum location of workpieces increases the optimization about 16% over the optimization of non-productive time of the initial workpiece location.

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