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Cellular Manufacturing System Design for Multi-Objective Criteria using Meta heuristic Approach

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Abstract: The present work involves Design of a cellular manufacturing system for M/s Sagar Asia Private Limited, Hyderabad, using metaheuristic methods of Genetic Algorithm and Simulated Annealing Algorithm and subsequently to compare the performance evaluation of the said algorithms. M/s Sagar Asia is manufacturing a wide variety of access solutions including Ladders, Mobile Scaffolds, Work Platforms, and Access Solutions. A five-phased methodology was adopted for this study. First phase was the study of metaheuristic methods for cellular manufacturing system design. Manufacturing industries production process was studied in the next phase. Third phase involved collection of manufacturing data. In the fourth phase, a bi-objective mathematical model for cell formation was developed with an objective of designing a cellular manufacturing system by minimizing inter cell material handling cost and minimizing workers penalty cost due to workers varying skill level. A metaheuristic algorithm (Genetic Algorithm and Simulated Annealing Algorithm) has been developed to solve the industrial problem. Fourth phase covers the coding of both algorithms in MATLAB. For solving the developed bi-objective mathematical model different arrangement of machines were considered. Method-I (single type of machine for each cell formation) and method-II (copy of machines were considered for all the cells). Finally, fifth phase covers the performance comparison of both the methods.

Keywords: cellular manufacturing system; Genetic Algorithm (GA); Simulated Annealing Algorithm (SA); Worker Assignment.

I. INTRODUCTION

Group Technology (GT) is a manufacturing philosophy in which similarities among the parts are identified and grouped together in order to exploit the advantages of their sameness in design and manufacturing. Cellular manufacturing (CM) is a production system in which similar parts are classified into part families dissimilar machines are assigned a common space or cell. GT may be considered as an interface between the process-based layout and product-based layout.[1][2].

II. DESIGN OF CELLULAR MANUFACTURING SYSTEM

Cellular manufacturing is an application of Group Technology in manufacturing in which all or a portion of firm's manufacturing system has been converted into cells. A manufacturing system is a cluster of machines or processes located in a close proximity and dedicated to the manufacture of a family of parts. The parts are similar in their processing requirements, such as operations, tolerances and machine tool capabilities the primary functions of implementing a cellular manufacturing system are to reduce setup time and flow time and thereby reduce inventories and market response time.

III. GENETIC ALGORITHM

Genetic Algorithms (GA) were formally introduced by Prof. John Holland, University of Michigan, Ann Arbor in 1975 and have been applied in a number of fields, e.g. mathematics, engineering, biology, and social science. GA is the most popular Evolutionary Algorithms technique. Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics. They combine the concept of survival of the fittest with structured, yet randomized, information exchange to form robust search algorithms. The concept of GA mimics the evolution process that occurs in natural biology.
The principles of the biological process of natural selection and the survival of the fittest are applied to the search of the solution of optimization problems. This approach is known as genetic algorithms which is a population-based metaheuristics. Genetic algorithm is an evolutionary method in which multiple pairs of solutions (parents) are modified to give rise to other solutions (children), who then have children themselves. First a pool of solutions (chromosomes) are generated which is the diversification phase of the search process. These solutions are encoded as binary, numeric or alpha-numeric strings. Then, parents are selected for reproduction out of this pool. The reproduction is achieved by various strategies of crossovers of the parents. Improvement is aimed to be obtained by selecting the competitive chromosomes that weed out poor solutions and carry over the genetic material

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to the offspring. The generated offspring's become the potential individuals of the population. The inferior solutions of the pool are discarded and the offspring's with better objective function values or the "fitness" values are replaced with them [3][4][5].

IV. SIMULATED ANNEALING ALGORITHM

Simulated annealing (SA) is one of the novel algorithms which were initially presented by Kirkpatrick et al. This algorithm, like other meta-heuristics algorithms, attempts to solve hard combinational optimization problems through a controlled randomization. Its ease of use and ability to provide a good solution for real-world problems make SA one of the most powerful and popular heuristics to solve many optimization problems.

In practical contexts, low temperature is not a sufficient condition for finding ground states of matter. Experiments that determine the low-temperature state of a material-for example, by growing a single crystal from a melt-are done by careful annealing, first melting the substance, then lowering the temperature slowly, and spending a long time at temperatures in the vicinity of the freezing point. If this is not done, and the substance is allowed to get out of equilibrium, the resulting crystal will have many defects, or the substance may form a glass, with no crystalline order and only metastable, locally optimal structures. A detailed analogy with annealing in solids provides a framework for optimization of the properties of very large and complex systems. This connection to statistical mechanics exposes new information and provides an unfamiliar perspective on traditional optimization problems and methods [6].

V. PROBLEM FORMULATION

There are some parts in the manufacturing system that each one has some operations which can be done on different machines. There are operators with certain specific skill to carry out operation on machines. It is required to identify parts which are having similarity in operation and needs to be put in a cell where it can be processed together. This prevents the movement of such parts to other sections for some operation on machines, which reduces or controls the inter cell movement. The whole effort is to produce similar parts in a single cell with required machines in that cell. Hence it is required to identify parts having similar operations so that that part can be put in a space and that space is called a cell. When various machines are arranged in a group, then it is required to shift the present work force to various cells. But workers may be having various skills for different machines, a less skilled worker may take long time to produce and will leads to loss to the firm. It may not be possible to provide best worker to all cells. Hence it is required to reduce the worker penalty due to their less skill for a particular machine on a cell.

The mathematical model (Appendix-I) has been formulated based on three dimensional machine-part-worker incidence matrix. The situation of model requires one to form multiple teams from a pool of candidates with necessary skills. The teams may consist of all or some of the available employees. This situation often occurs when converting to a new cellular manufacturing layout. The model assumes that the part machine cells have been predetermined, the set of employee skills for the cells has been evaluated, these skills are available in the pool of employees and each employee has been categorized as to the skill role they fill. The problem then becomes the selection of the appropriate employee for each role in the various cells in such a way that the team skill penalties are minimized. A mixed integer formulation of the part family/machine cell formation problem is formulated.

Assumptions:

(1) The number of parts is known in advance.

(2) Each part has a number of operations among which there is a chain precedence relation. However, there is no precedence constraint among different parts.

(3) Each operation of each part is processed at one machine. All worker types are multi-skilled. Each operation of each part only needs one machine with one worker to process. Workers in the same department working on similar machine posses equal skill level.

(4) The number of machine types and the number of machines of each type are known in advance. The number of machines and the number of workers are equal. One machine and one worker are grouped as a pair and assigned to a workstation.

(5) The processing of each operation of each part is not interrupted.

(6) The number of cells to be formed is given and is constant. The maximum and minimum of the cell size are specified in advance.

(8) The material handling devices moving the parts between cells are assumed to carry only one part at a time. Inter-cell material handing cost of each part is known. The cost is constant for one move between cells regardless of the distance. Intra-cell material handing cost was ignored.

Objective function

The objective function of the present model given in equation (1) minimises the overall system cost. The system cost includes material handling cost and workers skill penalty cost. The first term of the objective function is the inter-cell cost for each part type. This cost is sustained whenever the successive operations of the same part type are carried out in different cell. The cost is directly proportional to number of parts moved between two cells. In this model unit intercellular is expressed only as a function of part type being handled. The second term in the objective function shows the computation to minismise the worker skill penalty

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and to create a worker cell. First part of the objective function in Equation minimizes the number of inter-cell movements. The second part of objective function in Equation (1) minimises worker skill penalty.

Constraints

Equation (4) ensures that one part can be assigned only in one cell and equation (5) total number of assigned part in a cell should be greater than or equal to a specified value ‘θ’. Equation (6) ensure that the total number of parts assigned in a cell must be equal to the number of operation required to complete the processing requirement of part ‘i’. Equation (7) and equation (8) indicate that the machine assigned in a cell should be not less than m_{min} and not more than m_{max}. Equation (9) indicates that the machine assigned in a cell should be equal to the workers allotted in a cell. Equation (10) ensures that one worker can be assigned only in one cell.

VI. DEVELOPING GENETIC ALGORITHM

Genetic algorithm is an evolutionary method in which multiple pairs of solutions (parents) are modified to give rise to other solutions (children), who then have children themselves. First a pool of solutions (chromosomes) are generated which is the diversification phase of the search process. These solutions are encoded as binary, numeric or alpha-numeric strings. Then, parents are selected for reproduction out of this pool. The reproduction is achieved by various strategies of crossovers of the parents. Improvement is aimed to be obtained by selecting the competitive chromosomes that weed out poor solutions and carry over the genetic material to the offspring. The generated offspring’s become the potential individuals of the population. The inferior solutions of the pool are discarded and the offspring’s with better objective function values or the “fitness” values are replaced with them. The Algorithm Development steps are explained below:

Step 1. Scheme of coding

The algorithm steps starts with scheme of coding. Two methods of coding scheme were chosen for the work viz Method –I and Method-II. The main difference in both methods is in the development of chromosome string representation. Method-I is a basic coding system and a single chromosome string is used to represent the problem considered. Method –II is a more efficient chromosome string representation scheme. In this method, strings were used in multi layers.

Method I

For any GA implementation, the first stage is to map solution characteristics in the format of a chromosome string. Each chromosome is made up of a sequence of genes from a certain alphabet. In this work, a direct coding scheme has been used, that is the allele of each gene represents the cell number to which the machine or worker belongs. The chromosome representation consists of two sections. The first section represents the machines and the second stands for workers. The chromosomes used for the cell formation problem are represented as shown in figure 2.

First segment string represents a cell number and the positioning of the gene in the chromosome represents the machine number and second segment string represents a cell number and the positioning of the gene in the chromosome represents the workers number respectively. The length of the chromosome represents the number of machines and number of workers considered. The gene contains the cell number to which the machines are allocated. As shown in the chromosome structure, machine 1 is allocated at cell 1 and machine 2 is allocated at cell 3 and so on. Chromosome representation for all workers is given in figure 2. The chromosome structures have 9 genes for nine workers and machines.

	M/C No.									Worker No.								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Chromosome	**1**	**3**	**3**	**1**	**1**	**2**	**3**	**2**	**2**	**2**	**3**	**1**	**2**	**1**	**1**	**3**	**1**	**2**

Figure 1. Chromosome representation scheme (Method-I)

The gene contains the cell number to which the workers are allocated. As shown in the chromosome structure, worker 1 is allocated at cell 2 and worker 2 is allocated at cell3 and so on. This string is used considering a single type machine only in a cell. No copy of machine is considered in cells.

Method II

The string considered as a copy of machines in a various cell are represented using a 3 dimensional chromosome structure as shown in figure3, in order to take up the case of the industry under study, it was required to allocate copy of machines in various cells as per capacity. The industry under study is having copy of all machines.

In the method II, multi structured chromosome representation has been used. A copy of same machine has been considered for deploying in different cell. Some changes were made in the constraint numbered 3 of objective function as given below:

(i) cmax - Maximum number of same machines held by cell (<=No. of Cell)

(ii) cmin - Minimum number of same machines held by cell (<=No. of Cell)

A chromosome representation for a nine machines and their copy is given in figure 3. The chromosome structure has 9 genes in layer. The gene contains the cell number to which the machines are allocated. As shown in the chromosome structure, machine 1 is allocated at cell 1, cell 2 and cell3. Machine 2 is allocated at cell 2 and cell3. Machine three is in cell 1 and 3 and so on. This chromosome string was thus prepared.

	M/C No.									Workers No.								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
	2	**1**	**1**	**2**	**1**	**3**	**1**	**1**	**1**	**1**	**2**	**1**	**1**	**1**	**2**	**3**	**1**	**1**
Chromosome	**2**	**2**	**1**	**1**	**1**	**2**	**3**	**1**	**2**	**2**	**3**	**1**	**1**	**2**	**2**	**3**	**1**	**2**
	3	**2**	**3**	**1**	**2**	**2**	**3**	**2**	**3**	**3**	**3**	**3**	**1**	**2**	**2**	**3**	**2**	**3**

Fig 2. Chromosome representation scheme for copy of machines and workers

Step 2: Initialisation of the population
The second stage of GA implementation was to generate a set of initial solutions, called population. The number of initial solutions to be included in the population is called population size. The initial population was generated only once at the beginning for the first generation of the GA. Determining the proper population size is a major decision in GA implementation. The initial population of preferred volume was generated randomly in steps. In first step, the segment first of the chromosome was generated randomly considering feasibility of performing part operation on machines. In second step, segment second of the chromosome was filled randomly considering worker penalty cost on machines in a cell. Solution for given problem was represented by the embedded segments (genes) structure known as chromosome. Random string were generated depends upon the number of population chosen.
A strategy is applied with an objective to minimise the number of inter-cell move of parts. The part operations associated to each part type were assigned to machines existing in the cells. This process was repeated until all the parts are assigned to machines. Given a candidate part-machine assignment solution, the heuristic computes the number of inter-cell part transfer that would result minimum number of inter-cell transfer. Each string in the population was evaluated to find out the total cost F(x).

Selection rule
The Roulette Wheel selection procedure, as proposed by Goldberg **[7]**, was the selection strategy used in the present algorithm. The goal of selection strategy was to allow the ‘‘fittest” individuals to be considered more often to reproduce children for the next generation.

Fitness assessment
In GA implementation, a fitness function is used to evaluate and reproduce new chromosomes, called offspring for the generations to come. The purpose of the fitness function is to measure the goodness of the candidate solutions in the population with respect to the objective and constraint functions of the model. The descendants or new solutions are selected with higher fitness value obtained by playing binary tournament between parent solutions.
The objective function of the CMS design problem is to minimise the total cost. However, GA works with maximization functions. Thus necessary transformation from objective function to the fitness function was carried out in the following manner:

$$T(x) = \frac{1}{(1 + F(x))}$$

If the smallest objective function value is equal to zero, its value is set equal to 0.1. Thus the maximisation of the fitness value corresponds to the minimisation of the objective function (total cost) value.
Step 3: Comparing fitness value with next generation.
If fitness value is not improving then terminate.
Step 4: Perform reproduction on the population.
After evaluating the fitness value of chromosomes in the population, better performing chromosomes (parents) were selected to produce the descendants. Chromosomes with higher fitness value have a higher chance of being selected more often, which was achieved by playing binary tournament between parent chromosomes according to their fitness value.
Reproduction was carried out by using crossover and mutation operators on the selected parents to produce new offspring. Selection alone cannot introduce any new individuals into the population, i.e., it cannot find new points in the search space. These were generated by genetically-inspired operators, of which the most well known were crossover and mutation.
Step 5: Perform crossover on random pairs of strings.
Crossover combines information from two parents such that the two children have a ‘‘resemblance” to each parent. A single-point crossover operator is performed by randomly choosing a crossing site along the string and by exchanging all bits on the right side of the crossing site.

For method I, crossover was performed between two selected parent solutions which create two new child solutions by exchanging segments of the parent solutions, thus child solutions retain partial properties of the parent solutions. There are two segments in the chromosome one each for machine and the other for the worker. For crossover, the segments of two parents' solution are randomly mate following the matrix limits and the crossover probabilities. Random number is generated for this. The string representing machines and workers are undergone for cross over separately.
For method II, crossover was performed between two selected parent solutions on the same layer which create two new child solutions by exchanging segments of the parent solutions. Thus child solutions retain partial properties of the parent solutions. There are two segments in the chromosome one each for machine and the other for the worker. For a 2 cell system the chromosome structure have 2 layers each for machines and workers. For a 3 cell system the chromosome structure have 3 layers each for machines and workers. Likewise for 4 cells, it has 4 layered chromosome structures and so on. Figure 4 and 5 represent chromosome structure for a 3 cell CMS for machine and workers respectively. For crossover, the segments of two parent's solution are randomly mate following the matrix limits and the crossover probabilities. Random numbers were generated for this. Higher probability of crossover was used (0.8).
Step 6: Performing mutation on every string.
Mutation performs a secondary role in functioning of GAs. Even though crossover operator makes an effective search and recombines chromosome, yet it causes loss of some useful genetic properties. The mutation operator is implemented by inverting part of a gene in a parent chromosome to obtain child chromosome. A lower probability was chosen for mutation (0.05).

Repair function
The crossover and mutation operation may distort chromosome structure so as to yield infeasible solutions i.e. every cell may not have minimum number of machine type. The repair function was used to repair the distorted chromosome such that no machine type is left unassigned, and every cell gets minimum number of machines.

Termination of GA
The GA continues to create population of child solutions until a criterion for termination is met. A single criterion or a set of criteria for termination can be adopted. In this case the termination criterion is the maximum number of generation, i.e. the algorithm stops functioning when a specified number of generations are reached (Example 100).
Step 7: Evaluating strings in the new population. Then going to step3.

VII. DEVELOPING SIMULATED ANNEALING ALGORITHM

The name and inspiration come from annealing in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. Both are attributes of the material that depend on its thermodynamic free energy. Heating and cooling the material affects both the temperature and the thermodynamic free energy. The simulation of annealing as an approach that reduces a minimization of a function of large number of variables to the statistical mechanics of equilibration (annealing) of the mathematically equivalent artificial multi atomic system.
The probability of making the transition from the current state s to a candidate new state s' is specified by an acceptance probability function P(e, e', T) that depends on the energies e=E(s) and e'=E(s') of the two states, and on a global time-varying parameter T called the temperature. States with a smaller energy are better than those with a greater energy. The probability function P must be positive even when e' is greater than e. This feature prevents the method from becoming stuck at a local minimum that is worse than the global one.

Elements of the Simulated Annealing algorithm
A configuration represents a solution to the problem. In order to effectively use Simulated Annealing, a proper and intelligent solution representation structure was considered. The solution representation structure should allow easy manipulation during neighborhood generation process (i.e. it should be easy to generate new and feasible solutions). From this perspective, developing a solution representation structure may be considered as an art. In this study, an effective and novel solution representation structure is applied. A configuration was represented single and three dimension arrays of numbers called string for method I and method II respectively. The position of number represents the type of machines and value of number indicates the cell number. Consider the following string for a problem with three cells and ten machines.
For method-I copy of machine was not considered, and for method II copy of machine in cell was considered. This scheme of chromosome representation for method-I is shown in figure 4. Figure 5 shows a string for 3 cell 9 machine system for copy of machines in various cells. Coding for Simulated Annealing Algorithm were similar to Genetic Algorithm.

Neighbourhood-move
Transition from one configuration to another that results in a neighbor solution called a neighborhood move. In this work, neighbor solutions are generated as follows.
Step 1: In section one of the configuration, select different locations with different contents.
Step 2: Swap the selected elements in the chosen configuration.

Objective function

Objective function is a measure of the goodness of a solution. The objective function goes through the configuration after checking the number of machines in each cell and workers skill penalty.

Acceptance of a solution

The neighborhood solution is accepted if the objective function improves, otherwise the solution is accepted with a probability depending on the temperature, which is set to allow the acceptance of a large proportion of generated solutions at the beginning (high temperature). Then, the temperature is modified (lowered) to decrease the probability of acceptance. At each temperature a predetermined number of moves are attempted. Assume that x and y are two solutions with objective function values f(x) and f(y), respectively. Then the acceptance criterion determines whether y is accepted from x by applying the following acceptance probability:

$$P\{accepty\} = \begin{cases} 1 & \text{If } f(y) \leq f(x) \\ e(f(y)-f(x))/T & \text{If } f(y) > f(x) \end{cases}$$

Where T denotes the control parameter (temperature).A random number between zero and one is generated to get the 'p'. If p ≥ probability of selection, then accept f(y)

Stopping criterion

The proposed algorithm when no improvement in the solution is observed for a certain number of iterations. Specifically, when the objective function remains unchanged for 100 successive iterations, the algorithm stops running.

VIII. COLLECTION OF MANUFACTURING DATA

M/s Sagar Asia has two main plants, Plant-I and Plant-II. In plant I, aluminium extrusions are manufactured and in Plant –II access technology equipments are being manufactured. Access technology equipment covers non-self-supporting portable ladder, stepladder, Extension Ladder, Combination Ladder, Single sided, double sided access mobile work platform, etc. For this purpose, worker skill level was required to be estimated **[8].** Since the plant is working on a functional type lay out, all workers were equally expert in their filed. Hence workers in a single department were grouped together and assigned a skill level. Skill level is assigned as skill penalty. A skill penalty scale of 1 to 8 was considered for the present work **[10]**. A highly skilled worker on his machine is given a skill penalty of one. The importance of creating a worker cell helps in assigning a value to skill mismatching. The manufacturing data collected and the workers skill penalty matrix were collected from the industry for the present study **[20]**.

IX. ANALYSIS OF GENETIC ALGORITHM

The developed GA was coded using MATLAB simulation software with the manufacturing data of M/s Sagar Asia. For this 2016 version MAT LAB simulation software was used. Cost value for material handling, Different types of manufacturing cell formations and various worker cell formations were obtained by execution of the Genetic Algorithm.

Execution of Method-I:

In method-I of the GA, a cell with multi machines but no copy of any machine was considered. Initial inter department material handling cost per month was Rs.132,700.00 approximately. The algorithm was executed with a population size of 10 and generation size of 100 and for number of cells size from 2 to 5. Table 3 shows the outcome of Genetic Algorithm execution using Method-I.

The table shown in appendix II depicts the following:

The solution for GA was represented by chromosome string with genes as bit in it. The output of GA generation in terms of final or child chromosome string for machine in top (red in colour) and for worker below (blue in colour) is given in the third column. This string was obtained as output of algorithm execution. This string is in digital value from 1 to number of cells. For a 3 cell design this digit will be 1, 2 and 3. Machine string was generated by decoding the final chromosome string taken from third column. For the 2 cell problem, first machine cell consist of machine 1, 2, 3 and 4. This was obtained by looking at the position of the gene in the chromosome. First gene in the chromosome represents first machine (indicated by '1' in the chromosome structure) and numerical value of the gene represents the cell number hence first machine is in first cell. Second gene in the chromosome is again'1' and this represent second machine.

Part family was generated by looking at the cell, for parts having maximum similar operations in a particular cell were grouped as a family. Worker cell were generated in similar way, machine cell were developed by decoding the worker final string. Seventh column shows the cost value generated by the algorithm. This is the optimised (minimised) objective function value. This represents the least material handling cost in Rupees with respective cell design. Algorithm checks the objective function

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represented by equation (1), considering all constraints from equation (3) to (11) for the child string and returns the cost value. With the evolution of Genetic Algorithm, best child string was produced and this child string's calculated objective function value was returned as least inter cell material handling cost.

For method-I, cost value was increasing as the cell number increases, due to use of single type of machine in cells, not using copy of machines and increase in handling of materials in higher size cells. In 2 cell design, all parts are divided and put in to two cells, hence inter cell transfer of materials were less. But as the number of cell increases, the parts need a particular operation on a machine and that machine may not be available in that cell, inter cell handling cost also increases. This movement increases along the number of cells. The cost value obtained during the generation of cell size two was Rs. 7235.00. For cell size three, this cost was 4.53 times higher. For cell design four, the cost was 6 times higher than cell size three. The last cell size five generated a cost value of 1.63 times higher than the cell size four.

The execution of GA method-I for a 2 cell size problem took 13.16 seconds. For three cells design it took 16.95 seconds and four cell design it was 36.08 seconds. For a five cell generation the time taken was 205.21 seconds. First three executions took a lower time and generation of 5 cells took comparatively a higher time. The execution time depends upon the complexity of the problem. The algorithm needs to manage the allotment of parts and machines to cells and this process take time when cell size increases.
This design lead to movement of parts to other cell and created more inter cell transfers. This in turn increased the intercellular material transfer cost. The cost value in the method-I was not reduced to a satisfactory level. This was due to the reason that the designed cell was not fully equipped with all necessary machines. Hence parts need to move out of cell for next operation. For an industrial appliction, this design was modifeid using method-II for improved configuration of machines.

Execution of Method-II:
The results obtained from method-I was not satisfactory and this led to development of method-II. In method-II, copy of machines (duplicate machines) were used to reduce the inter cell movement. The industry under study was having copy of machines. The design allows a machine type to be present in more than one cell with parts being assigned based on part routings and the corresponding machine availability in a cell. Method –I was generating an unsatisfactory cost value for the cells. With a copy of machines in the cells, intercellular material transfer cost reduces to a satisfactory level. The execution of the algorithm was carried out with a population size of 10 and generation size of 100. Table (Appendix-III) shows the outcome of Genetic Algorithm execution using Method-II. Table shown in appendix II depicts the results obtained for cell number, final string for machine and worker, machine cell, part family, worker assignment, cost value and computational time in case of GA (method-II). By keeping copy of machines in cells, the inter cell transfer cost was reduced.

The two cell design need a minimum of 14 machines, for three cells 15 machines and 18 machines for four cells. The five cells design needs 25 machines. Two cell design make material handling difficult in a cell. In the industry under study, majority of parts are being processed through machine numbers 1,2,3 and 7(shearing, punching, drilling and welding machine). The second cell of two cell design holds machine numbers 1,2,3,5,6,7 and 8 and these machines need to process majority of parts. This makes the cell two to accommodate large number of parts. This will create more work in process inventory.

The cell size four, generates inter cell transfer similar to two cell design. The total machine requirement for this cell is 18. This cell design generates an inter cell transfer cost 1.4 times less than three cell and 1.5 times less than 5 cell design. Five cell size design need total of 25 machines. Considering the large number of parts in the second cell and high transfer cost involved in three cell design and five cell design as well as high machine requirement and capital investment needed in five cell design, the choice for implementing the design for industry is with four cell design. Keeping in view, the constraints of the present limited number of workshop sheds in the industry (though the industry has open space for expansion), it is recommended to have the 4 cell size design for the industry. The parts handled by the four cell design are balanced and manageable. Considering the above factors, four cell design is most suitable for the industry under study. To implement the cell system in the industry, the main cost factor involved is machine shifting and rearrangement cost. The industry needs to stop production for some days to carry out this rearrangement. Considering the cost of saving after cellular layout, the cost of stalling production and cost of rearrangement of equipment's and machines is justified.

X. ANALYSIS OF SIMULATED ANNEALING ALGORITHM

The developed SA Algorithm was coded using MATLAB (2016 version) simulation software. Appendix VI shows the outcome of the Simulated Annealing Algorithm execution obtained using Method-I. The Execution was carried out for a generation size of 100.
Execution of Method-I:
In method-I no copy of machine was considered to place in the cells. Every cell was given minimum and maximum number of machines without duplicate machine in cell. The solution was represented by two strings one for machine and the other for the worker.

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Aappendix IV shows the number of cell size, generated strings for machines and workers, machine cells decoded from the string, part family, worker assignment, cost value and computation time. Similar to method –I as used in the GA, the SA Algorithm works with a single line string for representing the solution for machines and workers. The string with 8 digits represents 8 machines and the digit value indicates the cell number. This method use only a type of machine to be allotted in a cell and no copy of machines were allowed. While comparing with GA the SA returns a higher cost value though SA Algorithm completes the computation within a very short period of time.

The variation of inter cell material transfer cost in case of SA Algorithm (Method-I) is shown Appendix IV. The two cell size generated a cost value of Rs.22,955.00 and the cell size three design returned a cost of 1.43 times higher than the cell size two. This higher cost is due to more movement of parts to other cells. Likewise, the four cell design cost value is 1.80 times higher than cell three. Five cell sizes makes more inter cell move and generates a cost value 1.25 times higher than fourth design.

Execution of Method-II:
The method-I generated solution with higher inter cell material handling cost value. Hence a second method was designed to reduce the cost, with copy of machine in the cell. The execution of the method-II generated satisfactory result and same is represented in table (appendix V). The cell size designed, string arrangement generated by algorithm, machine cell, part family, worker assignment, cost value and computational time are given in appendix V. The cell formations with method- II generated a better machine configuration with all constraints and return the minimum inter cell transfer cost.

The two cell design generated by SA Algorithm occupies more number of machines in a cell and makes the material handling difficult. Three cell size is better than two but handling of higher of parts in one cell again makes complicated material handling and large work in process. The industry under study was having a large floor space for expansion. The cell so formed makes no need of additional machine to be purchased than the existing capacity. The cell four sizes need a total of 17 machines. Considering the future increase in demand, the cell size four is the better option to be implemented in the industry.

XI. COMPARATIVE PERFORMANCE EVALUATION

In order to evaluate performance of the GA and SA Algorithm the industrial data from M/s Sagar Asia private Limited were used. Comparison was carried out for the performance of both the algorithms in term of the quality of final solution and the computational time. The solutions obtained by the Genetic Algorithm method were compared with the solution obtained with Simulated Annealing Algorithm for method- I in terms of the total cost function and total computational time as shown in table 1.

Table 1 Comparative Evaluation of the developed algorithms (Method-I)

Sl. No.	No. of cells	Cost/ month (in Rs.)			Computation Time (in seconds)		
		Genetic Algorithm	Simulated Annealing Algorithm	Variation (%)	Genetic Algorithm	Simulated Annealing Algorithm	Variation
1	2	7235.00	22,955.00	68.54	13.16	1.74	7.56 times higher
2	3	32,788.00	32,877.00	0.27	164.80	1.74	94.71 times higher
3	4	45,652.00	59,294.00	23.01	36.08	1.79	20.15 times higher
4	5	74,223.00	74,230.00	0.009	206.76	2.33	80.74 times higher

The variation in cost generated by GA and SA were not uniform. For the cell size two, it was 68.54% higher for SA algorithm. For cell size three, the variation in cost was marginal. The cost variation between four size cell design was 23.01% higher for Simulated Annealing algorithm. This variation in case of five cell design was negligible. The minimum variation observed in the cost value between GA and SA algorithm using method –I was 0.009% while generating cell size five and the maximum variation was 68.54% during second cell generation. It has been observed that the minimum variation in computational time taken by Genetic Algorithm with method-I is 20.15 times higher as compared to the SA Algorithm method-I for cell four design. The maximum variation is 94.70 times higher for cell three design.

Similarly, the outcome obtained by the execution of Genetic Algorithm were compared with the outcome of Simulated Annealing Algorithm for method- II in terms of the total cost function and total computational time. The table 2 shows size of the cell, inter cell material handling cost in rupees for both GA and Simulated Annealing algorithm, computational time taken by GA and Simulated Annealing algorithms and variation in cost and computational time.

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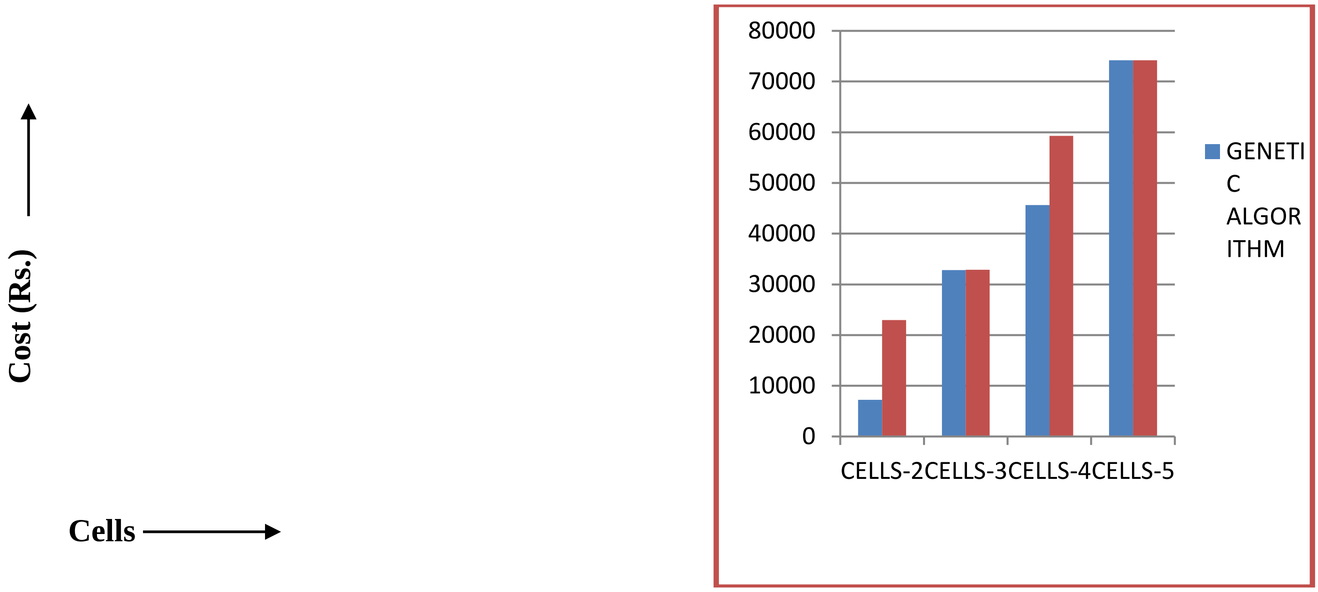

Figure-3 Variation of cost between GA and SA (Method-I)

A minimum variation in time taken for generating the outcome was noted as 9.29 times higher for GA in the case of cell size two and a maximum of 47.02 times higher in GA while generating cell number four.The Simulated Annealing algorithm generated higher cost value as compared to Genetic Algorithm in Method-II. Figure-3 sows' variation of cost between GA and SA (Method-I).

Table 2. Comparative Evaluation of the developed algorithms (Method-II)

No. of cells	Cost/ month (in Rs.)			Computation Time (in seconds)		
	GA	SAA	Variation (%)	GA	SAA	Variation
2	282.0	363.00	22.31	61.65	1.13	54.56 times higher
3	390.0	418.00	6.70	88.89	2.26	39.33 times higher
4	282.0	496.00	43.15	322.5	6.86	47.02 times higher
5	407.0	572.00	28.85	291.4	31.3	9.29 times higher

The comparison of the Genetic Algorithm and Simulated Annealing algorithm with the both method –I and II shows that Genetic Algorithm was giving a better outcome, but with a higher computational time. Many researchers **[9,10,11, 12,13,14,]** have worked with GA for designing cellular layout and recommended the algorithm for its effectiveness to generate a most befitting machine configuration and thereby recommending global minimum cost value. Mahdavi I**[14]** compared the performance of six various algorithms with GA for its effectiveness and showed that Genetic Algorithm works better than the other five including SA algorithms. The results obtained in the present work also show that these meta-heuristics are effective for cell design for industries.

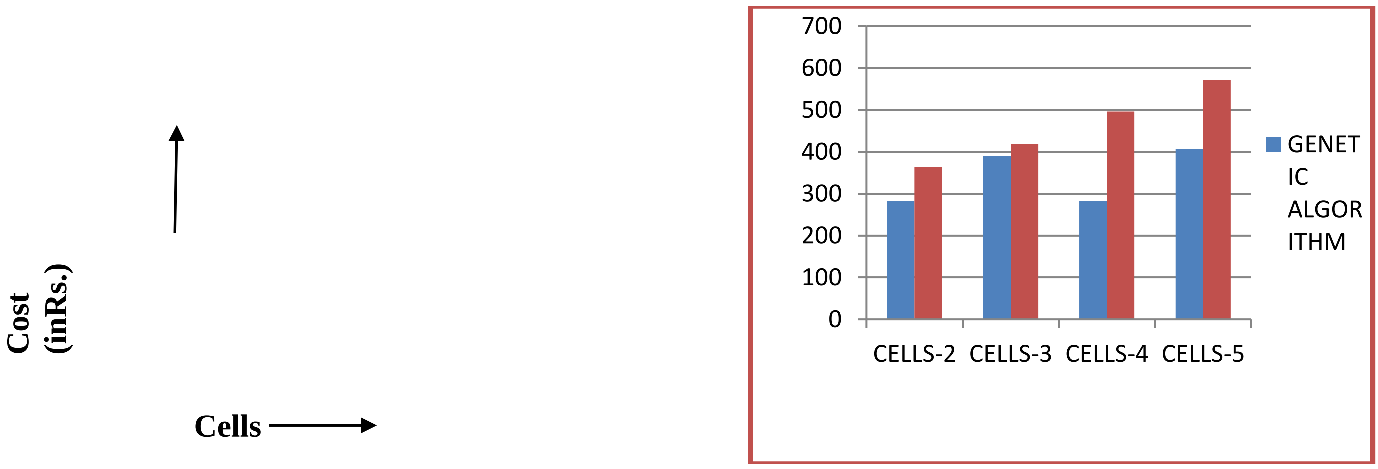

Figure-4 Variation of cost between GA and SA (Method-II)

From the functional layout of the industry under study with unit move from one to another, the inter departmental material handling cost is approximately around Rs. 1,32,700.00 in a month. This cost gets drastically reduced to a low value. The optimum configuration of the machines developed in this work for all the cell size gives least material handling cost. From the result obtained using method –II of Genetic Algorithm, it is noted that the cell size four performs better as compared to other cells. Keeping in view the constraints of the industry under study, the four cell design is recommended to be implemented in the industry. Figure-4 shows variation of cost between GA and SA (Method-II).

XII. CONCLUSION

In the present work, cellular manufacturing system design for multi objective criteria using meta-heuristic approach was adopted for M/s Saga Asia Pvt. Ltd, Hyderabad. A bi-objective mathematical model and meta-heuristic approach based on Genetic Algorithm and Simulated Annealing Algorithm were used for designing the cellular manufacturing system for the industry. A comprehensive manufacturing database was developed for the two meta-heuristic approaches used in designing the cellular manufacturing system design for the industry. After developing the codes for the algorithms and using the manufacturing database of the industry; the following conclusions are drawn:

- Genetic Algorithm and Simulated Annealing Algorithm have proved an efficient tool for providing optimal solutions for development of cellular manufacturing systems as evident from the recent research. These researchers have not used any industrial data in their work.
- The manufacturing volume and variety of products (mid volume – mid variety) in plant make it highly suitable for converting into a cellular layout.
- The developed GA (method-II) and SA Algorithm (method-II) were validated with bench mark data from earlier work and it has been found that it predict results better than the referred work.
- For solving the developed bi-objective mathematical model different arrangement of machines were considered. Method-I (single type of machine for each cell formation) and method-II (copy of machines were considered for all the cells).
- The solutions obtained by using the GA approach with method-I reduces the inter cell material transfer cost from the initial cost of Rs. 1,32,700.00 to Rs.7,235.00 for cell-2, Rs.32,788.00 for cell-3, Rs.45,652.00 for the cell-4 and Rs.74,223.00 for cell-5 respectively.
- GA approach was then used with method-II, resulting in drastic reduction in inter cellular material transfer cost with slight increase in computational time.
- In case of GA (method-I) the cell 2 and 4 design were taking less computational time as compared to three and five cell size design. Two cell design make material handling difficult in a cell. In the industry under study, majority of parts are being processed through machine numbers 1,2,3 and 7(shearing, punching , drilling and welding machine). This makes the cell two to accommodate large number of parts. This will create more work in process inventory.
- Keeping in view, the constraints of limited number of workshop sheds in the industry (though the industry has open space for expansion), it is recommended to have the 4 cell size design. Considering the cost of saving after cellular layout, the cost of stalling production and cost of rearrangement of equipments and machines is justified.
- Similarly, SA Algorithm was used for optimising the inter cellular material transfer cost by using method-I and method-II respectively. Here also the method-II gives better result as compared to method-I but still the inter cellular material transfer cost when compared to GA method-II is quite high, i.e. about 75.88% high.
- The variation in cost generated by GA and SA algorithm (method-I) were not uniform. For the cell size two it was 68.54% higher for SA algorithm. For cell size three the variation in cost was marginal. The cost variation between four cell size design was 23.01% higher for SA.
- A minimum variation of 6.70% in the inter cellular material transfer cost was observed between GA and SA, after its execution using method-II for cell number two. Similarly, maximum variation of 43.15% was observed in the case of cell number three.
- The SA (method-II) generated higher cost value as compared to GA (method-II).
- The comparison of the GA and SA with the both method –I and II shows that GA was giving a better outcome, but with a higher computational time. The results obtained in the present work show that the meta-heuristics are very effective for cell design for industries.
- From the result obtained using method –II of GA, it is noted that the cell size four performs better as compared to other cells.

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APPENDIX-I

Integer Programming Formulation:
System Requirements and Symbols-
α_i- Number of intercell transfers due to part i
β_i- Demand of part i
γ_i - Unit intercell transfer cost of part i
M_{ik} - Machine type required for the operation k of the part i
i – index of parts, i=1,2,…..N_p
j – Index of cells, j= 1,2,….. N_c
k - Index of operation, 1,2,….N_i
M – index of machines, M=1,2,….N_m
W – index of workers, W=1,2,….N_w
N_i - Number of operations required to complete the processing requirement of part i
m_{min} - Minimum number of machi\0
4 ne types per cell =1
m_{max} - Maximum number of machine types per cell
θ - Minimum number of parts per family
Z – Intercell material handling cost

- Number of part families = Number of machine cells.
- A machine type is assigned to various cells.
- Total workers in cell = total machines in cell
- When a part is assigned to a cell and some of the machines required for completing the operation required for this part are available in another cell, then the intercell transfer calculation needs to be done.
- This may be interpreted as that any movement of a part other than in the assigned cell has to be penalized. (That is, if a part is assigned to a cell then all its operation should be completed in the cell in which it is assigned.)

Decision variables

x_{ij} = 1 if part i is assigned to cell j
0 otherwise

$$\sigma\, M_{ik,j} = \begin{cases} 1 & \text{if machine part } M_{ik,} \text{is assigned to cell } j \\ 0 & \text{otherwise} \end{cases}$$

$$\textit{Worker assignment}, W = \left\{ \begin{matrix} 1 & \textit{if worker assigned to cell } j \\ 0 & \textit{otherwise} \end{matrix} \right\} \quad \forall\, w, j$$

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$$\text{Minimise } Z = \sum_{i=1}^{Np} \alpha_i \, \beta_i \, \gamma_i + \sum_{j=1}^{Nc} \sum_{w=1}^{Nw} W_{w,j} \sum_{m=1}^{Nm} W_{w,j} \, \boldsymbol{\sigma}_{m,j} \; {}_x \; S_{w,m} \qquad \_\_\_ (1)$$

$$\alpha_i = \sum_{j=1}^{Nc} \sum_{k=1}^{N\,i-1} x_{ij} \left[1 - \boldsymbol{\sigma}_{Mik,j} \times \boldsymbol{\sigma}_{Mi(k+1),j}\right] \qquad \forall i \qquad \_\_\_ (2)$$

Subjected to

$$\sum_{j=1}^{Nc} \sigma_{m_j} = 1 \qquad \forall m \qquad \_\_\_ (3)$$

$$\sum_{j=1}^{Nc} x_{ij} = 1 \qquad \forall i \qquad \_\_\_ (4)$$

$$\sum_{i=1}^{Np} x_{ij} \geq \theta \qquad \forall j \qquad \_\_\_ (5)$$

$$\sum_{k=1}^{Ni} \sum_{j=1}^{Nc} \boldsymbol{\sigma}_{Mik}, j = N_i \qquad \forall i \qquad \_\_\_ (6)$$

$$\sum_{M=1}^{Nm} \boldsymbol{\sigma}_{Mj} \geq m_{min} \qquad \forall j \qquad \_\_\_ (7)$$

$$\sum_{j=1}^{Nc} \boldsymbol{\sigma}_{Mj} \leq \mathrm{m}_{\mathrm{max}} \qquad \forall j \qquad \_\_\_ (8)$$

$$\sum_{w=1}^{Nw} \mathrm{W}_{w,j} = \sum_{m=1}^{Nm} \boldsymbol{\sigma}_{m,j} \qquad \forall j \qquad \_\_\_ (9)$$

$$\sum_{j=1}^{Nc} \mathrm{W}_{w,j} = 1 \qquad \forall w \qquad \_\_\_ (10)$$

$$\boldsymbol{\sigma}_{\mathrm{Mik}}, \mathrm{j}, \mathrm{x}_{\mathrm{ij}} = \{0,1\} \qquad \forall \mathrm{i}, \mathrm{k}, \mathrm{j} \qquad \_\_\_ (11)$$

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Appendix –II Outcome of Genetic Algorithm (Method-I)

Sl. No.	No. of Cell	Final String Machine child/ Worker child	Machine Cell	Part Family	Worker Assignment	Cost value (in Rs.)	Computation Time (in seconds)
1	2	1 1 1 1 2 2 2 2 2 2 2 1 1 1 1 2	{1,2,3,4}, {5,6,7,8}	{2,3,4,6,8,10,14,22, 28,41} {1,5,7,9,11,12,13,15,16,17,18,19,20,21,23,24,25,26,27,29,30,31,32,33,34,35,36,37,38,39,40,42,43,44,45,46,47,48,49,50,51,52,53,54,55}	{4,5,6,7,}, {1,2,3,8}	7235.00	13.16
2	3	1 3 1 2 2 3 2 3 2 2 3 2 1 3 1 3	{1,3}, {4,5,7}, {2,6,8}	{28,34,47,51} {14,15,16,17,18,21,22,30,31,32,33,35,36,37,40,41,42,43,45,46,50,52,54,55} {1,2,3,4,5,6,7,8,9,10,11,12,13,19,20,23,24,25,26,27,29,38,39,44,48,49,53}	{5,7}, {1,2,4,}, {2,6,8}	32,788.00	16.95
3	4	4 1 2 1 3 2 3 3 3 2 3 1 1 3 2 4	{2,4}, {3,6}, {5,7,8}, {1,8}	{1,3,4,5,7,9,11,12,19,20,23,24,25,26,27,44,48,49,53} {2,6,8,10,14,15,28,31,33} {13,29,38,39}{16,17,18,21,22,30,32,34,35,36,37,40,41,42,43,45,46,47,50,51,52,54,55}	{4,5},{2,7}, {1,3,6},{8}	45,652.00	36.08
4	5	5 3 3 2 1 2 4 1 4 3 5 2 3 1 1 2	{5,8}{4,6} {2,3}{8} {1}	{39} {20,34,43,47,49,51,53} {18,19,21,30,35,36,38,40,42,44,46,50,52} {1,3,4,5,7,9,11,12,13,16,17,23,24,25,26,27,29,48} {2,6,8,10,14,15,22,28,31,32,33,37,41,45,54}	{6,7}{4,8} {2,5}{3}	74,223.00	205.21

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Appendix –III Outcome of Genetic Algorithm (Method-II)

Sl. No	No. of Cell	Final String Machine child/ Worker child	Machine Cell	Part Family	Worker Assignment	Cost value (in Rs.)	Computation Time (in seconds)
1	2	1 1 2 1 2 1 2 1 2 2 1 1 1 2 2 2 1 1 1 2 2 2 2 1 2 1 1 2 1 2 2 1	{1,2,3,4,5,6,8} {1,2,3,5,6,7,8}	{15,19,20,30,33,44,49,53} {1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18,21,22,23,24,25,26,27,28,29,31,32,34,35,36,37,38,39,40,41,42,43,45,46,47,48,50,51,52,54,55}	{1,2,3,5,6,8} {1,4,5,6,7}	282.00	74.04
2	3	2 2 1 2 3 1 3 2 1 2 3 2 3 1 1 2 1 1 2 3 3 1 1 3 1 2 3 2 1 3 1 1 1 3 3 2 1 3 3 1 1 2 3 2 3 3 3 2	{1,2,3,6,7}, {1,2,3,4,8}, {3,4,5,7,8}	{1,3,4,5,7,9,12,14,16,17,18,21,22,24,25,26,27,28,30,32,34,35,36,37,40,41,42,43,45,46,47,48,50,51,52,54,55} {2,4,6,8,10,11,15,19,20,23,28,31,33,41,44,49,53} {13,29,38,39}	{1,5,7,8}, {2,4,8}, {2,3,5,6,7}	390.00	88.89
3	4	1 2 3 2 2 1 1 4 2 4 3 1 1 4 3 2 4 4 3 3 2 4 4 2 4 4 3 1 1 4 3 2 4 3 4 1 3 1 3 4 1 3 2 1 1 4 4 2 1 2 1 3 1 4 2 4 4 3 1 1 2 4 4 2	{1,4,5,6,7} {1,2,4,5,8} {3,4,7} {1,2,6,7,8}	{1,3,4,5,7,9,12,13,14,16,17,24,25,26,27,28,29,34,38,39,47,48,51} {2,6,8,10,11,15,19,20,22,23,30,31,32,33,37,41,44,45,49,53,54} {16,17,18,22,30,32,34,35,36,40,42,43,46,50,52} {21,24,27,38,40,55}	{1,3,4,5,6} {2,4,5,6} {2,4,7} {1,3,6,7,8}	282.00	322.53
4	5	3 3 1 4 5 2 2 1 4 2 4 3 4 5 5 5 5 2 4 2 4 5 4 2 4 1 3 4 4 5 1 1 5 3 4 4 1 5 1 3 5 1 1 2 4 1 5 4 5 2 5 2 1 1 3 2 3 4 3 3 1 1 3 2 5 4 1 5 4 2 2 5 3 4 4 1 1 3 4 4	{2,3,5,7,8} {2,4,6,7,8} {1,2,3,4,8} {1,3,4,5,7} {1,5,6,7,8}	{2,6,8,10,11,19,23,26} {3,4,22} {55} {13,29,38,39} {1,5,7,9,12,14,15,16,17,18,20,21,24,25,27,28,30,31,32,33,34,35,36,37,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54}	{1,3,4,7} {2,4,6,7,8} {1,3,46,7} {2,5,7,8} {1,3,4,7}	407.00	291.43

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Appendix –IV Outcome of Simulated Annealing Algorithm (Method-I)

Sl. No	No. of Cells	Final String Machine child/ Worker child	Machine Cell	Part Family	Worker Assignment	Cost value (in Rs.)	Computation Time (in seconds)
1	2	1 1 1 1 1 2 2 2 1 1 1 1 2 1 2 2	{1,2,3,4,5}, {6,7,8}	{1,,2,3,4,5,6,7,8,9,10,11,12, 14,15,16,19,23,24,25,26,27, 28,33,44,48,49,53}, {13,17,18,21,22,29, 30,31,32,34,35,36,37,38,39, 40,41,42,43, 45,46,47,50,51,52,54, 55}	{1,2,3,4,6} {5,7,8}	22,955.00	1.74
2	3	3 3 1 2 2 1 2 1 1 3 2 2 1 2 3 1	{3,8}, {4,5,7} {1,2,}	{2,3,4,6,8,10,14,26,28,31} {1,5,7,9,11,12,13,16,17,18,2 4,25,27,29,30,34,35,36,38,3 9,40,42,44,46,47,48,50,51,5 2} {15,19,20,21,22,23,32,33,37 ,41,43,45,49,53,54,55}	{1,5,8},{,4, 6}, {3,7}	32,877.00	1.79
3	4	2 4 3 1 4 2 1 3 2 2 1 4 1 3 4 3	{4,7},{1,6} , {3,8},{2,5}	{15,33} {11,12,13,19,20,23,29,38,44, 48,49,53},{1,2,3,4,5,6,7,8,9,1 0,14,16,17,18,24,25,26,27,28, 30,31,32,35,36,37,40,42,45,4 6,50,52,54} {21,22,34,39,41,43,47,51,55}	{3,5}, {1,2}, {6,8}, {4,7}	59,294.00	2.33
4	5	1 4 3 5 2 3 3 4 5 3 2 3 3 1 4 4	{1}{5}{3,6 ,7}{2,8}{4 }	{20,49,53} {43} {22,33,41} {34,39,47,51} {1,2,3,4,5,6,7,8,9,10,11,12,1 3,14,15,16,17,18,19,21,23,2 4,25,26,27,28,29,30,31,32,3 5,36,37,38,40,42,44,45,46,4 8,50,52,54,55}	{6}{3},{2, 4,5} {7,8},{1}	74,230.00	2.86

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Appendix –V Outcome of Simulated Annealing Algorithm (Method-II)

Sl. No.	No. of Cell	Final String Machine child/ Worker child	Machine Cell	Part Family	Worker Assignment	Cost value (in Rs.)	Computation Time (in seconds)
1	2	2 2 2 2 1 2 2 2 1 2 1 2 1 1 1 2 2 1 2 2 1 2 1 2 1 1 2 2 2 2 2 1	{1,3,5,6,7} {1,2,3,4,6,7,8}	{13,29,34,38,39,47,51} {1,2,3,4,5,6,7,8,9,10,11, 12,14,15,16,17,18,19,20, 21,22,23,24,25,26,27,28, 30,31,32,33,35,36,37,40, 41,42,43,44,45,46,48,49, 50,52,53,54,55}	{1,2,5,7,8,} {1,3,4,5,6,7, 8}	363.00	1.13
2	3	2 2 2 1 3 1 3 3 2 2 1 2 3 3 2 1 1 2 3 2 3 3 2 3 1 3 1 2 1 3 2 3 3 3 3 1 2 1 2 2 2 2 1 1 1 1 2 2	{1,3,4,6,8}, {1,2,3,4,7}, {3,5,6,7,8}	{ 12, 16,17, 20, 21,22, 23, 30,33, 34, 35, 36, 40, 41, 42, 43,44,46,48,49, 50, 51, 52,53,55} {1, 2, 4, 5, 6, 7, 8, 10, 11, 14, 15, 18, 19, 26, 27, 28, 31, 32, 45, 54} {3, 9, 13, 24, 25, 29, 38, 39, 47}	{1,3,4,5,6} {1,2,4,5,7,8} {1,2,3,6,8}	418.00	2.26
3	4	2 1 2 3 2 4 1 3 3 2 3 1 2 1 2 4 2 2 1 3 2 3 1 4 3 1 4 3 2 1 4 3 1 3 2 2 4 1 4 1 1 3 2 4 1 2 3 1 3 4 3 2 1 3 4 2 3 4 3 1 4 3 2 2	{2,4,6,7} {1,2,3,5,7} {1,3,4,6,8} {3,6,8}	{16,19,21,23,30,55} {1,4,5,6,7,8,9,10,11,13,1 4,15,17,24,25,26,27,28,2 9,31,32,37,38,39,54}, {2,3,12,14,16,18,20,32,3 3,40,45,46,47,48,50,52} {18,22,30,34,35,36,41,4 2,43,44,49,50,54}	{1,4,5,6,8} {3,4,6,7,8} {1,2,3,6,7} {2,4,5,7}	496.00	6.86
4	5	4 1 4 5 4 3 4 2 5 1 5 1 4 3 4 2 4 1 3 3 3 3 5 2 1 5 4 1 2 2 4 2 2 4 2 3 4 2 3 1 5 4 4 5 5 3 4 2 2 1 2 4 3 2 5 1 4 1 2 3 2 5 1 3 5 3 2 3 4 2 4 2 4 4 4 1 3 2 5 2	{1,2,4,8} {1,3,5,6,8} {3,4,5,67} {1,2,3,57} {1,2,3,4,7}	{21,22} {2,3,4,6,8,10,26} {13,29} {11,15,19,20,23,31,33,3 4,38,39,44,47,49,51,53} {1,5,7,9,12,14,16,17,18, 21,24,25,27,28,30,32,35, 36,37,40,41,42,43,45,46, 48,50,52,54,55}	{1,2,3,7} {2,3,5,6,8} {2,4,5,6,8} {1,2,3,5,7} {1,4,5,6,7}	572.00	31.36