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Cutting Stock Problem: A Solution Based on Novel Pattern Based Chromosome Representation Using Modified GA

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***Abstract*—The cutting stock problem (CSP) is an important problem in class of combinatorial optimization problems because of its NP-hard nature. Cutting the required material from available stock with minimum wastage is a challenging process in many manufacturing industries such as rod industry, paper industry, textile industry, wood industry, plastic and leather manufacturing industry etc. The objective of this research work is to propose Novel Pattern Based Chromosome Representation Using Modified Genetic Algorithm for multiple stock size cutting stock problem (MSSCSP) and Single Stock Size Cutting Stock Problem (SSSCSP). The main challenge in solving cutting stock problem is to develop chromosome representation for MSSCSP in GA. Moreover, this paper test results on 8 large data set with LP, 10 large data set with EP and Two-Swap algorithm. Our proposed algorithm gives better results than LP in MSSCSP, EP in SSSCSP and Two-Swap algorithm in SSSCSP.**

Keywords*— *Cutting Stock Problem (CSP), Novel Pattern based Chromosome Representation, Modified GA, Meta-heuristic Techniques, Multiple Stock Size Cutting Stock Problem

I. Introduction

The cutting stock problem (CSP) is an important class of combinatorial optimization problems. It addresses the practical issue of how to cut the material based on required lengths from the given stock with minimum wastage. In general terms, it is the problem of deciding about from which stock to cut which items such that customer requirements are satisfied and incurred waste is minimum. This problem occurs in many real-world manufacturing industries such as rod [7], paper [2], wood [3], steel [15], etc. Due to NP-Hard nature of CSP, cutting stock is a challenging problem, whether it is single stock or multiple stock problem. It requires more attention when available stock of is multiple size.

To solve the cutting stock problem, many techniques exist such as heuristic and meta-heuristic. Survey of existing techniques and chromosome representation used to solve cutting stock problem is respectively presented in [15] and [1]. Since then, many new techniques have been applied for solving the cutting stock problem. However, to the best of our knowledge, no concise survey of existing techniques and chromosome representation to solve cutting stock problem is available in the literature. Meta-heuristic techniques are important because they have ability to guide local search heuristic in order to allow it to escape local optima.

This paper compares various meta-heuristic techniques including GA, Evolutionary Programming (EP), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO) and GSA (Genetic Symbiotic Algorithm) etc., with evaluation parameters such as accuracy and speed of convergence. Moreover, This paper surveys various research paper for one-dimensional CSP based on several parameters such as chromosome representation, global and local optimization and fitness function. From the survey, we found that solving MSSCSP using genetic algorithm is an interesting research topic and it was attempted by only Araujoa et al. [6] and that also for limited items. Moreover, this paper makes comparison of various chromosome representation based on their method and disadvantage.

As the success of GA and Evolutionary Computing based solution depends on proper chromosome representation, this paper surveys various chromosome representations and also presents drawbacks of each representation. Certain chromosome representations are available in literature but that are applicable to single stock size cutting stock problem (SSSCSP). Therefore, we have proposed chromosome representation based on modified GA for MSSCSP and SSSCSP.

The summary of this research paper is as follows. Section II provides a Literature review. Section III provides proposed Methodology with proposed Novel chromosome representation. Section IV provides Experiments and results with large dataset. Section V. provides Conclusions.

II. Literature Review

A. Comparison of Meta-heuristic Techniques for Csp

Several meta-heuristic techniques have been used to solve cutting stock problem. We presented a comparison of GA, EP, ACO, PSO etc. with evaluation parameters such as accuracy and speed of convergence. The comparison is presented in Table I.

Some basic idea about Meta-heuristic techniques are as follows. In Tabu Search, the iteration always try move to the best solution of the neighborhood even though it would be worse than the current solution. In GRASP, the algorithm restarts searching for solution from other promising region to escape local minima of the search space until a local optimum is obtained. The main difference between the EA, genetic GA and EP is that GA uses crossover as a primary operator and mutation as a secondary operator whereas EP uses only mutation [15]. EA can't called Meta-heuristic algorithms because it will not use a lower level heuristic. However, EA are often hybridized with TS or local search heuristic. ACO uses pheromone strategy of real ants to find the shortest path between the nest and a food source.

Liang et al. [10] has proposed CSP without contiguity, which is better than GA in terms of trapping into local minima. However, it fails to compete with HGGA (Hybrid Group based Genetic Algorithm) [13], which combines local search approach of GA with the best solution method of BPP (Bin packing problem). ACO is quite slow in execution but the good point about it is that it has steady performance and when it does not find optimum solution, it still tries to find a good solution [18].

According to the summary of Survey of Metaheuristic technique, the methods can be ranked as ACO, EP and GA in relation to accuracy of the solution and in terms of speed of convergence ranked as EP, GA and ACO.

B. *Comparision of Chromosome representation and Literatutre review*

In Table I, we have describe summary of various chromosome representation and its method and disadvantage off that chromosome representation [20].

TABLE I
COMPARISON OF CHROMOSOME REPRESENTATION FOR CSP

Author	Method	Cons
Falkenauer [13]	Item Chromosome represented as the groups of items	1. can't use traditional crossover operator, so, we have to mutate for made them feasible, not proper global exploration
Jin Peng Zhang Shu et al.[16]	Pattern Based chromosome representation using multi-chromosome	1. Only for SSSCSP not for MSSCSP, 2. Same problem of crossover as above.
Araujo et al [6]	Matrix based chromosome representation	1. Only apply to limited stock size problem because generation of large cutting pattern
Rodrigo et al[8]	Pattern based chromosome representation using Co-evolutionary GA	1. Only applicable to SSSCSP not for MSSCSP.

In second Part of Section surveys solving cutting stock problem using meta- heuristic techniques including GA, EP, ACO and GSA that are shown in Table II [20]. The survey parameters include chromosome representation, global and local optimization, and fitness function. Weakness of described chromosome representation are that It can solve only single chromosome representation or it can be applied for only limited stock size. Binitha et al. [3] applied GA that uses variable length chromosome representation. First chromosome defines stock size (jumbo) and second chromosome defines items (reels) cut from that stock. Khalifa et al. [4] provided chromosome representation in which each chromosome was processed in pairs of gene; the first gene in each pair would give the pattern number to be used and the second gene would give the no. of times this pattern would be used in the solution. Liang et al. [5] provided multi chromosome representation in which first chromosome provide the items to be cut and second chromosome provide the cut point and third chromosome provide calculation of wastage. Araujo et al [6] provided matrix representation, where each gene was represented by a cutting pattern (a_{jk}) and also the number of times it was cut (x_{jk}). Therefore, an individual is represented as a matrix where a column represents a cutting pattern and the number of times it was cut for a specific stock size. The number of column can be different for each matrix because it depends on different cutting patterns. The number of rows is equal to the number of different items plus a row of the number of times the cutting pattern is cut. Péter et al. [7] provided tree based representation, where each node represent cutting pattern. Golfeto et al. [8] have provided single chromosome representation in which solution is processed as a pair of gene. First gene represents the cutting pattern and frequency of that Pattern is represented by the second gene.

TABLE II
SUMMARY OF LITERATURE SURVEY

Author	Binitha S et al.(2012)[3]	Y.khalifa and O.Salem and A.Sachin(2006)[4]	Ko-Hsin Liang et al.(1998)[5]	K.Eshghi, H.Javanshir[14]	Ko-Hsin Liang et al.(2002)[5]
Problem	Paper roll cutting	Cutting stock, one dimensional	Cutting stock problem	One dimensional cutting stock problem	CSP with & without contiguity
Method	Genetic algorithm	Genetic algorithm	Evolutionary programming	ACO	Genetic algorithm
Objective	Minimize trim loss by minimizing no. of jumbos used	Minimize waste	Minimize waste	Minimize total cost of waste material	Minimize waste
Representation	Two chromosome, variable length	Single chromosome	Order based multi chromosome representation: (1. Item, 2. Cutpoint, 3. Wastage)	-Ant is cut point -pattern oriented approach	Multi chromosome representation
Fitness	Waste	Minimizing waste while meeting demand of each length	-Minimizing waste -Minimizing No. of stock with wastage	Probabilistic rule	Minimizing no. of stock with wastage
Method to achieve Global optimization	Two point/ one point cross over	Problem specific crossover	None	None	Uniform order based crossover
Method to achieve Local optimization	Random removal & reinsertion of one element	Problem specific	-CSP without contiguity:3 point swap -CSP with contiguity: Stock remove & insert (probability based)	-Local search procedure Pheromone deposited on pattern -If minimum loss get than previous replace.	3-point swap Mutation
Percentage of Waste Reduction	It is not mentioned	28.92%	It is not mentioned	Faster than column generation by 37 second	It is not Mentioned

Author	Silvio A. Araujo et al.(2010)[6]	ANDRÁS Péter[7]	Rodrigo Rabello Golfeto[8]
Problem	Evolutionary approach for 1-D CSP	Cutting stock problem using GA	Genetic Symbiotic algorithm (GSA) For muti objective CSP
Method	Evolutionary Algorithm	Genetic Algorithm	Genetic Symbiotic Algorithm
Objective	To minimize waste	To minimize waste	Multi objective: Cost of : trim loss & setups
Representation	Matrix representation	Tree based representation	Linear Single chromosome representation
Fitness	Minimization of waste	Minimize waste while meet demand of each length	Minimization of waste
Method to achieve Global optimization	Repeat exhaustion reduction heuristic for construct solution	Combined crossover	Uniform crossover
Method to achieve Local optimization	Not mentioned	Combined cross-over mutation	Two-point swap mutation
Percentage of Waste Reduction	It is not mentioned	9.5% wastage Given dataset	It is not mentioned

III. PROPOSED WORK

This section describes proposed novel pattern based chromosome representation. It also describes proposed GA based methodology, crossover and mutation on Pattern based population.

A. Proposed Novel "Cutting Stock Pattern" Based chromosome representation for Multiple size Stock Cutting Stock Problem

This research work solves Multi stock size cutting stock problem using GA. In this approach, solution is process in pair of gene in that first gene of each solution represents frequencies of cutting pattern and cutting pattern is represented by second gene. In pattern population, first gene describes the stock size and remaining describe the frequencies of items according to its index and last gene describes wastage of that pattern.

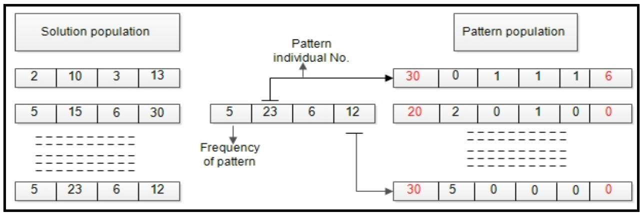

Figure 1 Novel Pattern Based Chromosome Representation

Fig. 1 describes the cutting-stock pattern individual; in that size of cutting pattern will be (type of items + 2).

For ex. Customer Requirement (item) : {6, 7, 8, 9}, in fig. item chromosome shows 6m of zero, 7m of one, 8m of one, 9m of one quantity will be cut from 30m of Stock size.

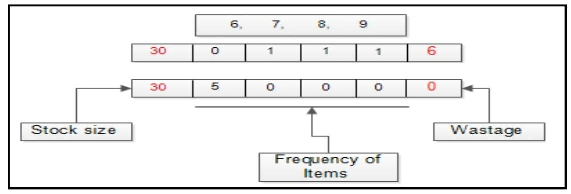

Figure 2 Description of pattern chromosome

B. Proposed Architectur modified GA

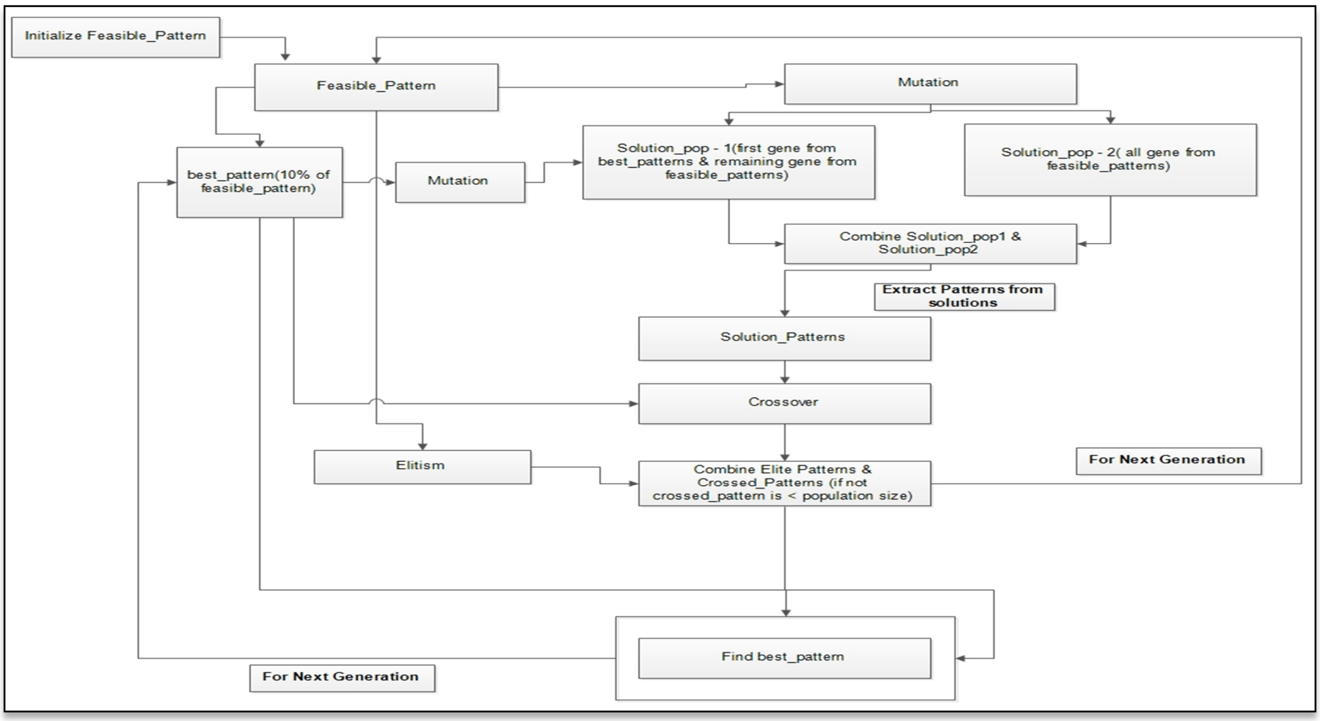

Figure 3 Proposed architecture for Cutting Stock Problem using Modified GA

Proposed Modified GA Algorithm:

1. Generate initial feasible cutting pattern and store it in "_feasiblePattern".
2. Calculate fitness of feasible patterns
3. Select 10% of best pattern and store it in "_bestPattern".
4. Generate solution population-1: for generation of a Solution first pattern will be selected from "_bestPattern" and all other patterns are randomly selected from "_feasiblePattern".
5. Generate solution population-2: this step selects random patterns from "_feasiblePattern".
6. By combining both solution population 1&2, solution population will be generated.
7. Then, this research work extract patterns which were used for generating solutions, and store it in "_soutionPattern".
8. One-point crossover will be performed between patterns, in this step parent-1 will be selected from "_bestPattern" which will be first pattern of that array and parent-2 will be selected from "_solutionPattern", this will be repeated for all pattern of "_solutionPattern", output of crossover will be stored in "_crossedPattern"
9. Then, elitism will be performed for "_feasiblePattern" and fittest pattern will be selected from "_feasiblePattern".

10. For new generation of "_feasiblePattern", we combine "elite patterns" and "_crossedPattern" , we update "_bestPattern", by selecting best cutting pattern from previous "_bestPattern" and Newly Generated "_feasiblePattern".

11. Apply mutation on "_bestPattern" and "newly generated _fesaiblePattern" will be done while generation of solution.

12. This step will repeat until stopping criteria is satisfied.

C. Crossover on Pattern Individual

For Crossover we select first Pattern from "_best_Pattern" as Parent-1 and for Parent-2 we select first pattern from "_feasible_Pattern", we will do crossover until all Patterns of _Feasible_Pattern are selected as Parent-2 with first Patterns of "_best_Pattern", then same will be repeated until all Patterns of _best_Pattern is selected as Parent-1.

In crossover we will not consider first digit because it shows stock size and also not last digit because it shows wastage, we update wastage accordingly, and in crossover we select only same stock size pattern otherwise there will be more possibility of generating infeasible child.

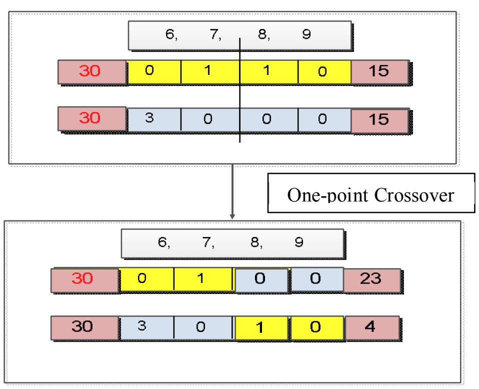

Figure 4 Crossover for Pattern Population

We perform mutation on pattern while generating solution, then randomly select bit of pattern and generate random number.

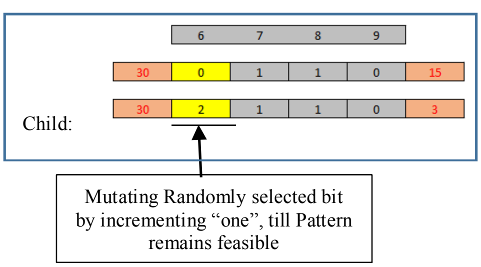

Figure 5 Mutation for Pattern Population

Within counter limit then replace it with selected bit and then check feasibility of pattern if it is not feasible, then put bit as it is. We have used 20% mutation probability.

IV. Experiments and Results

A. User Interface

1. *Input as CSV : Provide input Items and Stock in csv file as given format*

Items k1,5,3-
"k1" describes part-id & "5,3" describes 5m of 3 items.
Stock- indicates available stock size of material which is 20m and 25m.

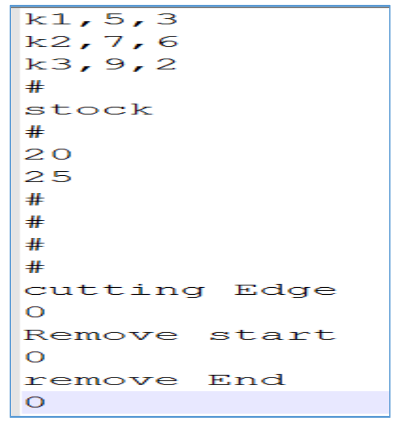

Figure 6 shows Input as CSV: Provide input Items and Stock in CSV file as given format

2. Input GUI:

The left side panel shows available Stock and right side panel shows items and its quantity.

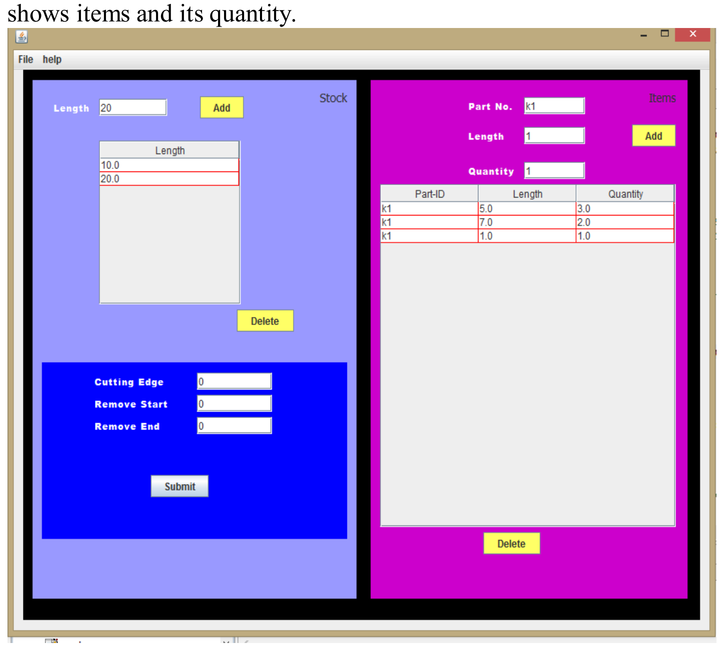

Figure 7 shows snap shot of Input GUI

3. Output GUI

Red line with number defines Stock size, rectangle with cut defines item, if there is red portion then it defines wastage and left side digit defines quantity of that rod.

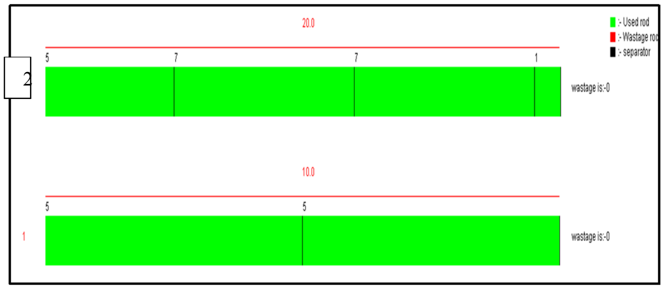

Figure 7 shows snap shot of Output GUI

B. presented test-data, results and comparison with other algorithm

In our experimental studies, 18 test Problems were used, the detailed description of those problems are given in Liang et al. [5]. Liang et al. have proposed EP for multi-objective CSP and different fitness function but we'd discovered that the wastage of function was similar for them as well as for us. So, we found it necessary to compare only result of wastage. The 18 problems can be divided into two parts: The first part contained 8 benchmark problems, in that total required items ranging from 20 to 400. Problem 1-8 are Multiple Stock Cutting problems and 1a to 10a are Single Stock Cutting problems. In second part, other 8 problems contains required items ranging from 20 to 600. These selected benchmark problems will be helpful for comparing our new proposed Genetic Algorithm approach with Linear Programming, which is implemented using Pattern Generation Simple Heuristic with "LPsolve55j" library and also with EP and Two swap algorithm. Liang et al. [5] have calculated results for Two-Swap with 6a to 10a benchmark problems. In which all possible patterns are generated for finding feasible patterns, suppose "M" items and "N" stock, then for one position of pattern there is possibility of representing digit is "M*N*(D^N)", where D is Maximum Possible digit that can be placed into that position. So, for large number of items, it is difficult to find solution within given time. Below given is one of the best result out of 20 mean result for Proposed GA.

Table III Comparison of Multiple Stock Cutting problem with LP

Prob. No.	Req. items	Proposed GA (total wastage)	Linear Programming(total wastage)
1	20	0	4
2	50	0	12
3	60	1	6
4	60	4	6
5	126	700	766
6	200	61	79
7	200	64	119
8	400	181	210

Sum of all total wastage for proposed GA is "1011" and for LP is "1202", which shows 8.4% wastage reduced than LP in MSSCSP.

Table IV Comparison of single stock cutting problem with EP and Two-swap algorithm

Prob. No.	Req. items	Proposed GA (Total wastage)	Evolutionary-Programming(Total wastage)	Two-swap(Total wastage)
1a	20	3	3	Not given
2a	50	14.5	13	Not given
3a	60	2.5	0	Not given
4a	60	11	11	Not given
5a	126	10850	10966	Not given
6a	200	330.9	319	488.28
7a	200	327.6	190	465.60
8a	400	547.95	788	944.00
9a	400	673.8	730	955.60
10a	600	662.5	1037	1073.20

Sum of all total wastage for Proposed GA is "13499" and for LP is "14057", which shows 9.5% wastage reduced than EP in SSSCSP. For 6a to 10a, sum of all wastage for proposed GA is "3064" and for two-swap "3926", which is 7.5% less than it.

CONCLUSION

In this research paper, the survey of various chromosome representations have been done and the novel pattern based chromosome representation was proposed. This research work also proposed a modified GA based algorithm for solving cutting stock problem. And finally, it is concluded that according to proposed chromosome representation for wastage reduction was much better i.e. 8.4% than that of LP with MSSCSP; as well as 9.5% better than that of EP with SSSCSP and 7.5% better than that of two-swap with SSSCSP. The proposed modified GA based solution of cutting stock problem was tested over large data set of items requirement ranging from 20 to 600.

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