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Address: -North Asian International Research Journal Consortium (NAIRJC) 221 Gangoo, Pulwama, Jammu and Kashmir, India - 192301, Cell: 09086405302, 09906662570, Ph. No: 01933-212815, Email: nairjc5@gmail.com, nairjc@nairjc.com, info@nairjc.com Website: www.nairjc.com

GENETIC ALGORITHM BASED WORKFORCE OVERTIME CAPACITY PLANNING & SCHEDULE CELLS

MOIN-UL-ISLAM AHANGER [1] & MR. AMIT AHLAWAT [2]

Research Scholar, Dept. of Mechanical Engineering CBS Group of Institutions Jhajjar, Haryana India [1]
Assistant Professor, Dept. of ME, CBS Group of Institutions Jhajjar, Haryana India [2]

ABSTRACT

The problem studied in this thesis was observed in an actual company. The problem is more complex than usual scheduling problems in that we compute over time requirements and make scheduling decisions simultaneously. Since having tardy jobs is not desirable, overtime work is allowed to minimize the number tardy jobs or total tardiness. Problem, to maximize the total profits by delivering jobs on or before time. The tardy jobs in this case are considered as lost sales. In problem mathematical model is presented reflecting different overtime workforce hiring practices. To solve the same problem for one particular hiring policy, a Genetic Algorithm (GA) approach is also discussed. GA includes some newly proposed mutation operators, dynamic and twin. The proposed twin mutation strategy produced the best results in all problem sizes. Experimentation has been carried out using five instances each based on the data collected from the company. For most problems, the mathematical model gave results in seconds. Earlier we saw that lot of job was tardy, so lost sale of these jobs as solving these problem by making a mathematical model and taking overtime decision and optimize profit we got that after solving through MATLAB no. of tardy job was very less and profit increase. For all observations are represented through graphical interpretation finally mean deviation for all five set of data within all four strategies(GA1,GA2,GA3,GA4),GA2 provides best Result for setting A, setting B, setting C for given data & for setting D, setting E GA4 shows best result.

Key Word- ***Capacity Planning, Schedule Cells, Genetic, Algorithms, Matlab.***

1. INTRODUCTION

This chapter describes Group Technology, Cellular Manufacturing System (CMS), Capacity Planning in CMS, Overtime Decision Making, Solution Approaches, Computer Programming Language, Mathematical Modeling, Genetic Algorithms (GA), Thesis objective, and Justification.

1.1 GROUP TECHNOLOGY

Group Technology (GT) is a manufacturing philosophy which exploits the similarities among the manufacturing parts to improve the performance of manufacturing system by reducing the material handling cost, throughput time, and work-in-process inventory. The most similar products are grouped and processed together on manufacturing cells. The grouped products are treated as a product family.

1.2 CELLULAR MANUFACTURING

Job shops and flow lines cannot meet today's production requirements where manufacturing systems are often required to be reconfigured to respond to changes in product design and demand. As a result, cellular manufacturing (CM), an application of group technology (GT), has emerged as a promising alternative manufacturing system. Within the manufacturing context, GT is defined as a manufacturing philosophy identifying similar parts and grouping them together into families to take advantage of their similarities in design and manufacturing. CM involves the formation of part families based upon their similar processing requirements and the grouping of machines into manufacturing cells to produce the formed part families. A part family is a collection of parts which are similar either because of geometric shape and size or similar processing steps required in their manufacture. A manufacturing cell consists of several functionally dissimilar machines which are placed in close proximity to one another and dedicated to the manufacture of a part family.

Manufacturing industries are under intense pressure from the increasingly-competitive global marketplace. Shorter product life-cycles, time-to-market, and diverse customer needs have challenged manufacturers to improve the efficiency and productivity of their production activities. Manufacturing systems must be able to output products with low production costs and high quality as quickly as possible in order to deliver the products to customers on time. In addition, the systems should be able to adjust or respond quickly to changes in product design and product demand without major investment. Traditional manufacturing systems, such as job shops and flow lines, are not capable of satisfying such requirements.

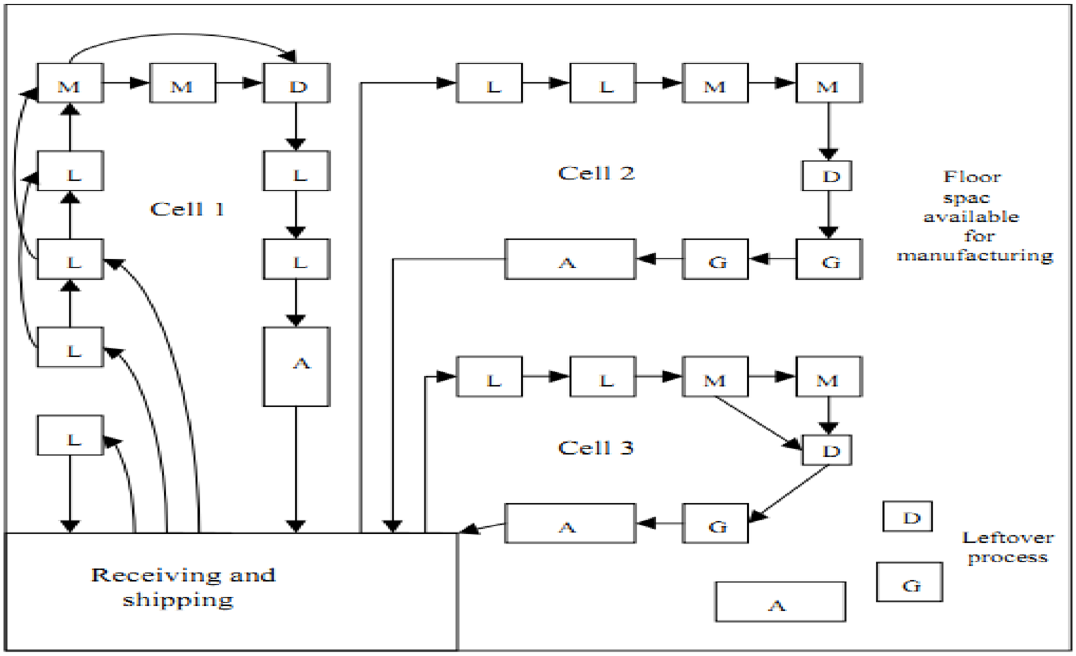

Figure 1.1 Cellular Manufacturing Layout

The two main aspects in CMS with respect to products assignment to the cell category are Cell Loading, and Cell Scheduling. Cell Loading is a decision making activity for planning the production in CMS with multiple manufacturing cells. The products are assigned to manufacturing cells based on the demands of products, their due dates, process times, and the production capacity of the manufacturing cells (Süer, Saiz, Dagli and Gonzalez, 1995, Süer, Saiz and Gonzalez, 1999).[1,2] Cell Scheduling, on the other hand, is a decision making activity for sequencing the products in each cell in CMS. It also includes start time, and completion time of the products in the cell. After having the information about the completion time of all the products, one can compute the tardiness or earliness of each product based on their due dates.

1.3 OBJECTIVE OF THE THESIS

The problem discussed in this thesis was inspired from a company. The problem is more complex than usual scheduling problems in that we compute overtime requirements and make scheduling decisions simultaneously. Since having late (or tardy) jobs is not desirable, overtime is allowed to; Problem maximize the profits generated by on-time delivered products, However, overtime also costs to the company and therefore there is a need to balance overtime and tardiness costs.

1.4 JUSTIFICATION OF THE THESIS

The uniqueness of the problem studied in this thesis is that we require computing workforce overtime requirements and making scheduling decisions simultaneously to maximize profit generated from delivered products and to minimize total tardiness and overtime costs. The review of the literature shows that this problem has not been addressed before. Therefore, it was taken as the research topic in this thesis. It is obvious that by increasing the capacity of the system by allowing overtime work, more products will be completed before their due dates and hence revenue will increase and tardiness penalty costs will decrease. On the other hand, overtime will bring additional costs as well. The thesis attempts to find the optimal amount of overtime work that will 1) maximize profit to be obtained from on-time delivery of products for problem.

2. LITERATURE REVIEW

2.1 INTRODUCTION

Several researchers focused on cell loading problem. Among them, Süer, Saiz, Dagli and Gonzalez, 1995, developed several simple cell loading rules for connected and independent cells, respectively. They have tested the performance of these rules against four different performance measures, namely number of tardy jobs, maximum tardiness, total tardiness and utilization. A total of 48 rule combinations were compared and no single combination dominated the others. It was also observed that n_T, T_{max} and TT behaved similarly. In a later study, Süer, Saiz and Gonzalez, 1999 analyzed the same problem for independent cells case and found similar results. Süer, Vazquez and Cortes, 2005 developed a hybrid approach of Genetic Algorithms (GA) and local optimizer to minimize number of tardy jobs in a multi-cell environment [3]. There are a number of works reported where both cell loading and product sequencing tasks are carried out. Süer and Dagli, 2005 and Süer, Cosner and Patten, 2009 discussed models to minimize make span, machine requirements and manpower transfers [4]. These works first assigned products to cells to minimize make span and then sequenced the products to minimize manpower requirements. Yarimoglu, 2009 developed a mathematical model and a genetic algorithm to minimize manpower shortages in cells with synchronized material flow. Synchronized material flow allowed material transfers between stages at regular intervals (e.g., 4 hour in his case).

Some other researchers studied the sequencing of families in a single cell or machine. Nakamura, Yoshida and Hitomi, 1978 considered sequence-independent group setup in his work and his objective was to minimize total tardiness [4]. Hitomi and Ham, 1976 also considered sequence-independent setup times for a single machine scheduling problem [5]. Ham, Hitomi, Nakamura and Yoshida, 1979 worked on minimizing total flow time keeping minimum number of tardy jobs by developing a branch-and-bound algorithm for the optimal group and job sequence[6]. Pan and Wu, 1998 focuses on minimizing mean flow time of jobs subject to due date satisfaction in a single machine scheduling problem. The jobs were categorized into groups without family splitting. Gupta and Chantaravarapan, 2008 worked on minimizing total tardiness with no family splitting allowed by considering group technology philosophy in single machine scheduling problem [7]. In the problem, individual due dates and independent family setup times are considered. Süer and Mese, 2011 studied the same problem but allowed family splitting as it would be beneficial in many cases [8].

2.2 SCHEDULING USING GENETIC ALGORITHMS

In this section, a brief survey of the attempts to apply Genetic Algorithms to scheduling problem will be discussed. This literature survey is by no means exhaustive. It is presented as a representative discussion of the various Genetic Algorithms strategies adopted and reported in the literature. At the end of this section, a table summery of the various Genetic Algorithms scheduling approaches is presented in terms of 4 dimensions, viz, the problem is investigated, individual representation. Crossover operator and mutation operator.

In [Mattfeld et al, 1994], the standard job shop problem is used to illustrate the implementation of a Genetic Algorithms approach that mimics "social-behavior" patterns to counter the problem of premature convergence [9]. The standard job shop problem refers to a static job shop scheduling problem where there are n jobs, each with m operations and there are m machines in the job shop. The objective of the scheduling problem is to sequence the various operations of the jobs to the machines so that the makespan is minimized. The benchmarked, standard job shop problems in [Muth and A gene or allele in this representation is a job and this allele is repeated m times (where m is the number of operations and the number of machines in the workshop). The ith occurrence of an allele refers to the ith operation of the job. The crossover operator is the order- crossover operator and mutation involves the position-based random change of alleles.

In [Tamaki and Nishikawa, 1992], Genetic Algorithms based on the neighborhood model is applied to a Job Shop scheduling problem. This problem differs from the standard Job Shop problem in that the number of operations in a job need not necessarily equal the number of machines in the job shop. The performance measure of the scheduling problem is make span.

3. PROBLEM STATEMENT

3.1 INTRODUCTION

The problems studied in this research were inspired from an actual company. In every planning period (week) there are *n* jobs to complete using *m* number of identical cells. Manufacturing cells are popular in the manufacturing world. The benefits of cellular manufacturing are lower setup times, smaller lot sizes, lower work-in process inventory and less space, reduced material handling, and shorter flow time, simpler work flow. Cellular Manufacturing also simplifies planning and control of various tasks floating on the shop floor. Cells are ideally equipped with all of the machines needed to produce a product or product family (Independent) and usually follow uni-directional flow (flow shop).

In this research, it is assumed that each job has its own individual due date. The modeling gets complicated in that we need to decide additional capacity requirements at the same time we make scheduling decisions.

3.2 PROBLEM: TO MAXIMIZE TOTAL PROFITS

Any job that cannot be completed by its due date becomes tardy and is assumed lost sales. Having tardy jobs is not desirable as this adversely affects relationships with customers and thus reputation of the firm in the long term. As a result, we allow overtime to minimize the number of tardy jobs. Overtime decisions are made for shifts on a daily basis. Overtime can be done during the weekends (Saturday and Sunday) as well as weekdays. Weekend overtime is done prior to upcoming week. It is also assumed that weekend overtime cost is higher than weekday overtime cost. The overall objective is to maximize profits. Tardy jobs are avoided as long as profit to be made is higher than the corresponding production/overtime costs. There are limitations on weekday and weekend overtime capacities. In this problem, the weekend overtime duration considered is 8 hours, the weekday overtime duration considered is 3 hours, and the number of shifts considered is 2. The weekend overtime shifts are back to back whereas the weekday.

Overtime shifts are before the corresponding regular shifts. Model can easily be modified to accommodate 1 shift. However, if the company wants to adopt a 3-shift policy, then weekday overtime option has to be eliminated and overtime can only be done during weekends. Lot splitting is not allowed in this study.

A numerical example is described in Table3.1 and3.2 to illustrate the problem studied. A 10-job and 2-cell example is used for this purpose shown in Table 1.Table 3.2 shows the Early/Tardy jobs computation for without Overtime option and it can be seen that Job 10 is tardy due to lack of enough capacity. Whereas, by performing Overtime on Tuesday shift1 on Cell 1, Job 10 can be saved., the overtime decision making in the case when overtime work option is available, respectively.

Table 3.1. 10-job 2-cell example

Jobs	1	2	3	4	5	6	7	8	9	10
Processing time	4.03	5.43	3.86	3.10	3.20	5.87	1.71	2.71	7.04	6.66
Due time	9.32	11.01	12.78	13.31	16.46	18.22	18.88	20.12	20.41	21.24

4. METHODOLOGY

As a solution technique, an optimizing approach is used to solve both of the problems. A Meta-Heuristic procedure is also developed to solve Problem and its performance is compared with the optimization approach in the study. Mathematical Model is proposed based on the current overtime workforce handling policies then their performance is compared. A GA application is also developed and discussed in this chapter for one of the policies. The performance of GA is compared with the respective Mathematical Model as well.

4.1 INTEGER PROGRAMMING FORMULATION OR MATHEMATICAL MODELING

Maxwell, 1970 developed a mathematical model to minimize number of tardy jobs on a single machine. Later, Süer, Pico and Santiago, 1997extended this model for parallel machine scheduling [18]. In a later study, Süer, Arikan and Babayiğit, 2008, 2009 adapted this model to cell loading problem where jobs are assigned to cells and number of cells and manpower levels for each cell are identified simultaneously. Süer, Mathur and Ji, 2011 extended these models where due date equations are modified to allow for overtime decisions. In the models proposed in this research, the due dates of jobs are modified in a similar way to meet different working conditions. This modification allows us to consider overtime decisions along with cell loading and scheduling. The main logic behind this formulation is that the due time for a job is extended (increased) by the total overtime hours planned before this job is due.

4.2 MATHEMATICAL MODEL

The model has been first proposed by Süer, Mathur and Ji, 2011. The unique feature about this model is that a uniform overtime strategy is applied, i.e., all of the cells get to do the same overtime whenever an overtime decision is made. This may be important in some companies where all the workers are given the same opportunity to do overtime and gain additional income. Overtime workforces are hired and paid for the complete period of overtime slot on all cells.

Indices:

i job index

j cell index

t day index

q Shift index

Parameters:

n number of jobs

m number of identical cells

$p_{[i]}$processing time of job in ith order (in hours)

$d_{[i]}$due time of job in ith order (in hours)

$shift_{[i]}$ shift in which ith job is due

$day_{[i]}$ day in which ith job is due

$s_{[i]}$ sales price of job in ith order

cwd weekday overtime cost per shift

cwe weekend overtime cost per shift

day_i due day of job i depending on due time

otwd length of weekday overtime (3 hours)

otwe length of weekend overtime (8 hours)

In this case, overtime decision variable is simplified as shown below

ot_{tq} 1 if there is overtime on day t in shift q,

0 otherwise.

The objective is to maximize the net profit as shown in equation. The first set of constraints (equation 1) enforce that early jobs are completed before their due times (original or extended). The second set of constraints (equation 2) guarantees that a job can assigned to at most one cell.

Objective Function:

Maximize z =

$$\sum_{i=1}^{n}\sum_{j=1}^{m} s_{[i]} * x_{[i]j} - cwd * m * \sum_{t=1}^{5}\sum_{q=1}^{2} ot_{tq} - cwe * m * \sum_{t=6}^{7}\sum_{q=1}^{2} ot_{tq}$$

Subject to:

$$\sum_{j=1}^{k} p_{[i]} * x_{[i]j} \leq d_k + otwd * \sum_{t=1}^{day_{[k]}}\sum_{q=1}^{shift_{[k]}} ot_{tq} + otwe * \sum_{t=6}^{7}\sum_{q=1}^{2} ot_{tq}$$

For k=1,2……..n .For j=1,2……………….n

$\sum_{j=1}^{m} x_{[i]j} \leq 1$For i=1,2…………..n

,$x_{[i]j}, ot_{tq} \, \epsilon \, (0, 1)$

4.3 GENETIC ALGORITHM

A GA is developed for solving the problem, considering all the assumptions and overtime work policies stated in Mathematical Model. Later in Chapter 6, the performance of the developed GA is compared with the Mathematical Model. The only small difference between Mathematical Model and developed GA application is that if there is only one weekday overtime needed, it can happen on a day or shift before it is needed in Mathematical Model 3 but in the corresponding developed GA application, it will happen always on Monday shift 1. But this will not change the overall objective because the cost and duration of weekday overtime is same irrespective of the day or shift it is being performed. But if we decide to include earliness penalty than this feature of GA has to be improved, to be compatible with the corresponding Mathematical Model.

5. A NUMERICAL ILLUSTRATION

An example case is illustrated in this section. Model are solved using GA and the GA application is developed and solved using MATLAB 7.12 (R2011a).

5.1 NUMERICAL ILLUSTRATION OF PROBLEM

A 20-job and 2-cell problem is solved by mathematical model. In mathematical model illustration, three tables and one figure are given. The first table shows the sequence of jobs assigned to each cell; the second table shows the corresponding overtime decisions for the problem; the third table shows the original due day, due shift and due time; revenue generated from each job, processing times, detailed computations of completion times and revised due dates (di*) based on overtime decisions; and the Gantt chart is given in the corresponding figure. It is important to note that the weekend overtime starts before the week starts. For example, to complete a job before the set due date (say on Monday evening), overtime can be performed on Saturday and/or Sunday shifts.

Table 5.1: Given DATA

Job	Due Day	Due Shift	Processing Time	Due time	Sales Price
1	Monday	1	3.01	5.79	2424.38
2	Monday	2	11.70	13.75	3539.11
3	Tuesday	1	10.61	17.11	2451.80
4	Tuesday	1	5.41	18.44	1792.35
5	Tuesday	1	12.89	19.08	3733.76
6	Tuesday	1	13.32	19.49	3748.54
7	Tuesday	1	4.93	20.96	1696.70
8	Tuesday	1	15.35	21.04	2147.59
9	Tuesday	1	3.42	22.21	1430.30
10	Wednesday	2	9.47	45.36	1299.49
11	Wednesday	2	6.40	45.90	1913.32
12	Wednesday	2	8.07	46.06	3092.46
13	Thursday	1	5.37	52.81	2799.01
14	Thursday	1	11.74	54.82	1629.80
15	Thursday	2	14.09	58.18	3914.95
16	Thursday	2	10.86	59.30	2483.75
17	Thursday	2	14.16	60.35	2026.68
18	Friday	1	6.20	64.15	1799.68
19	Friday	1	7.73	64.62	1110.93
20	Friday	1	10.20	70.69	3483.41

Table 5.2: Step required for solution

Step 1 Jobs are assigned to between two cell by using MATLAB code

Cell	Jobs
C1	2,3,6,7,9,12,13, 14,18,19
C2	1,4,5,8, 10,11,15,16,17 ,20

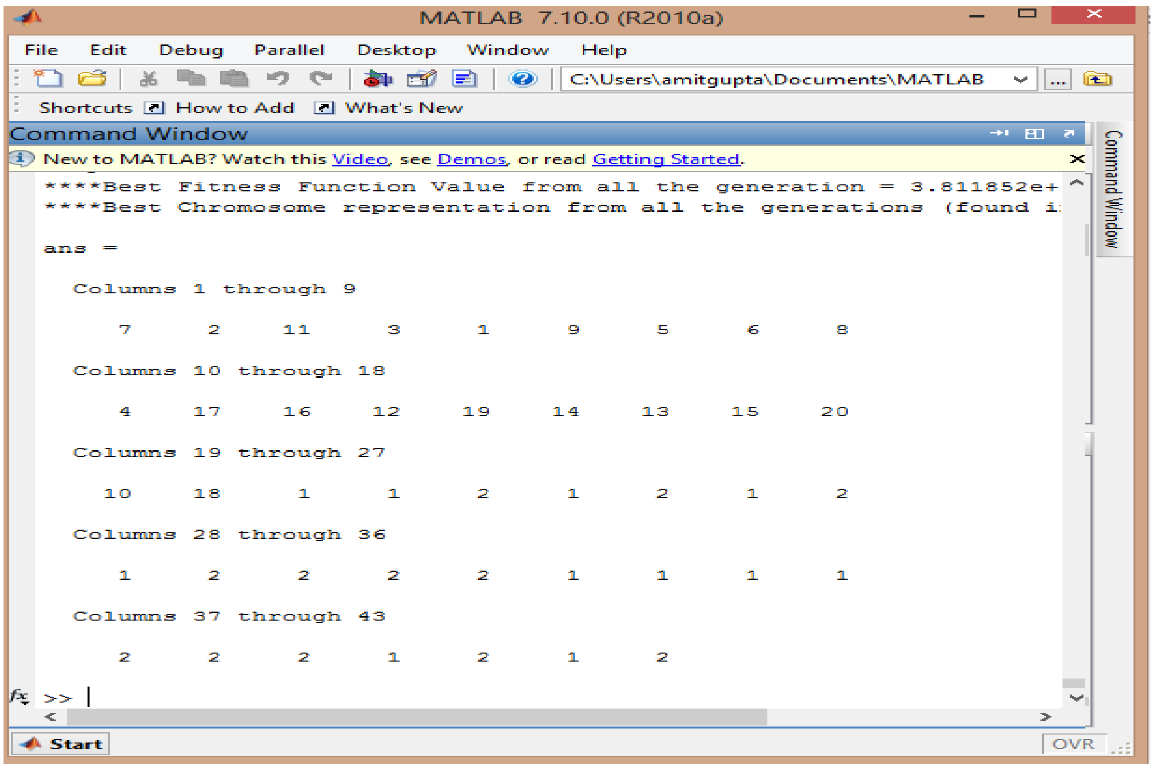

Figure5.1 Example of Snap Shot Form Matlab

5.3 SOLUTION BY DEVELOPED GA APPLICATION

An example case is illustrated in this section. Table 5.3 shows a chromosome for 20-job 2-cell problem. Table 5.3 shows the corresponding overtime decisions for the same chromosome. Table 5.3 shows the original due day, due shift and due time; processing times, detailed computations of completion times and revised due dates (di*) based on overtime decisions. In Table 5.3, for example Job 1 is due Monday, shift 1, and original due time is 19. Since we allow overtime on Sunday for 8 hours for shift1 & 2and also allow 3-hour overtime for shift 1 on Monday, the due date is taken as (d1*=) 24.79 (=5.79+8+8+3). Similar adjustments are made for all jobs, i.e. jobs original due.

5.3.1 Solution by developed GA-1

Case: 1

Parameter setting for solution

Crossover probability =0.7 Mutation probability =0.3 Population=200 Generation=300

Crossover Type = Order based Mutation type=Random Type

Table5.3: RESULTS: - Job allocation Decision: for G1

Cell	Jobs
C1	1,2,3,5,10,16,17,19,20,8
C2	4,6,7,9,11,12,13,14,15,18

Table5.4: for Overtime decisions for model GA-1

Day	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Shift1	0	1	1	0	0	0	0
Shift2	0	1	1	0	0	0	0

Figure5.2-Snap Shot From MATLAB for GA-1

6. OBSERVATIONS & RESULTS

In this section, experimentation results are discussed. Mathematical Model are developed and experimented. Genetic Algorithms are developed and experimented in MATLAB 7.12 (R2010a).

Different problem sizes are considered for the experimentation. Five different instances of data (means different processing times, due dates and sales prices) are chosen for each problem size. This is done to observe the effect of different data on the same size problem (means having the same number of products and same number of cells). The data generated is inspired from the Company where the problem was observed. Each product undergoes eight different operations. The upper and lower range of processing times for each operation was identified based on the sample data provided by the company. The processing times were generated randomly from this interval for the corresponding operation in each data set. Processing times for operations 1, 2, 3, 4, 5, 6, 7 and 8 follow uniform distributions UD(2, 4), UD(1,2.5), UD(1, 3.5), UD(1, 2), UD(1,2), UD(1, 2), UD(1, 2), and UD(0.2, 2), respectively. The batch size of each product follows uniform distribution UD(50, 250). The production rate for each product is identified based on the bottleneck machine. The processing time (hr) for a job is computed dividing its batch size with its production rate. The due time of each job is generated by using equation 22. Due days of products are calculated on the basis of due time (considering one week as a period).

$$d_i = P_i + \left[\frac{\sum_{i=1}^{n} P_i}{n}\right] * UD(1,10)$$

Where P_i = processing time; d_i= due date; n = no. of jobs

6.1 EXPERIMENTATION RESULTS OF PROBLEM

Eight problems were formed with 20, 30, 40, 50, 60, 70, 80 and 90 jobs/products; and 2, 2, 2, 2, 2, 4, 4 and 5 cells, respectively (problems 1, 2, 3, 4, 5, 6, 7 and 8, respectively). The hourly labor rates for regular time, weekday overtime and weekend overtime are taken as \$10, \$15, and \$20, respectively. The weekend overtime is limited to 8 hours per shift whereas weekday overtime is restricted to 3 hours per shift. The sales price of each job is assigned by using equation

$S_i = P_i *200*[1+UD (0.25,0.5)]$

6.2 MATHEMATICAL MODEL VS GA FOR PROBLEM

In this section, a performance comparison between different GA strategies are discussed and compared to mathematical model results. Later, a best GA strategy is chosen based on statistical analysis and an exhaustive comparison and experimentation is performed between best GA strategy and mathematical model.

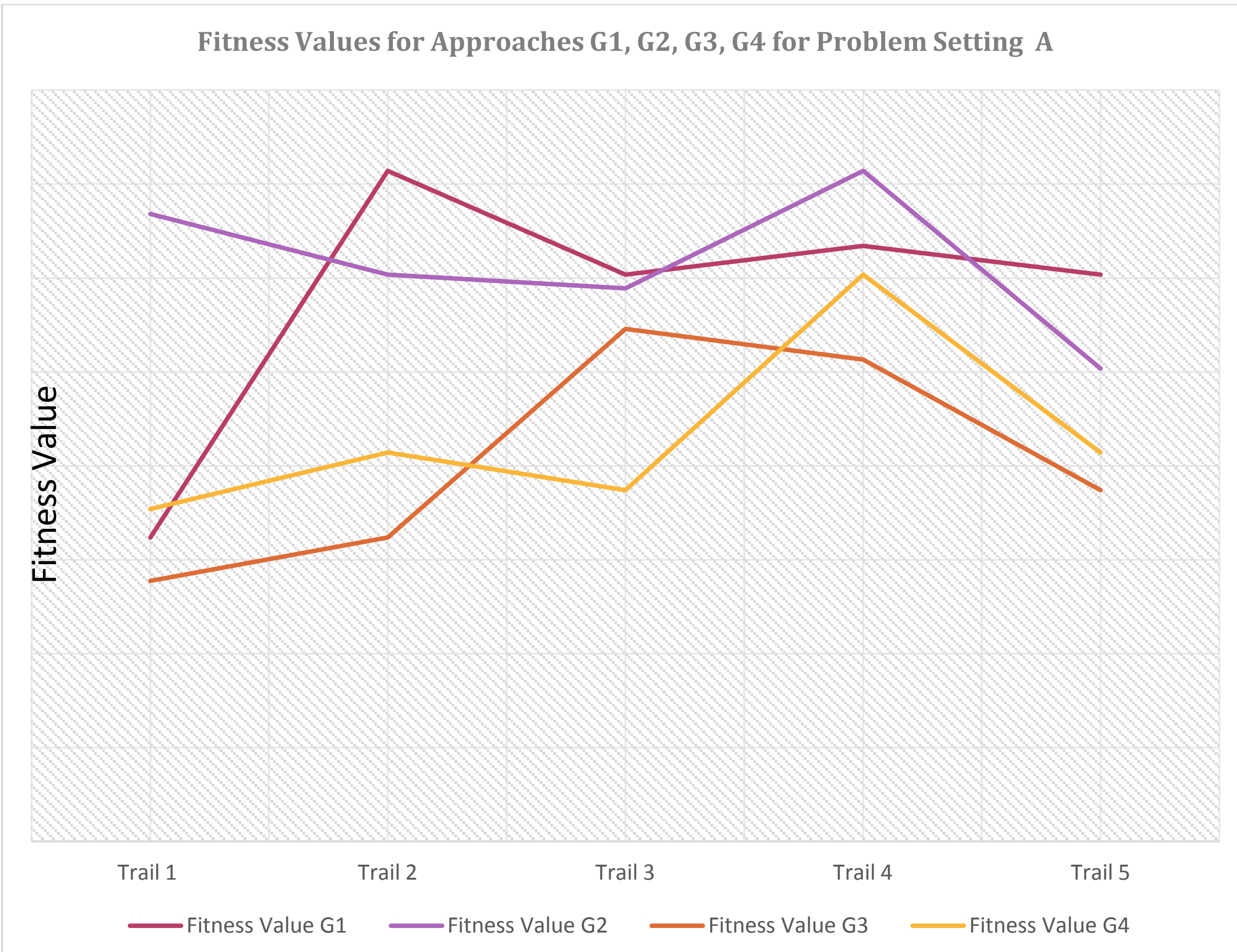

Fig. 6.1: Fitness Values for Approaches G1, G2, G3, G4 for Problem Setting A

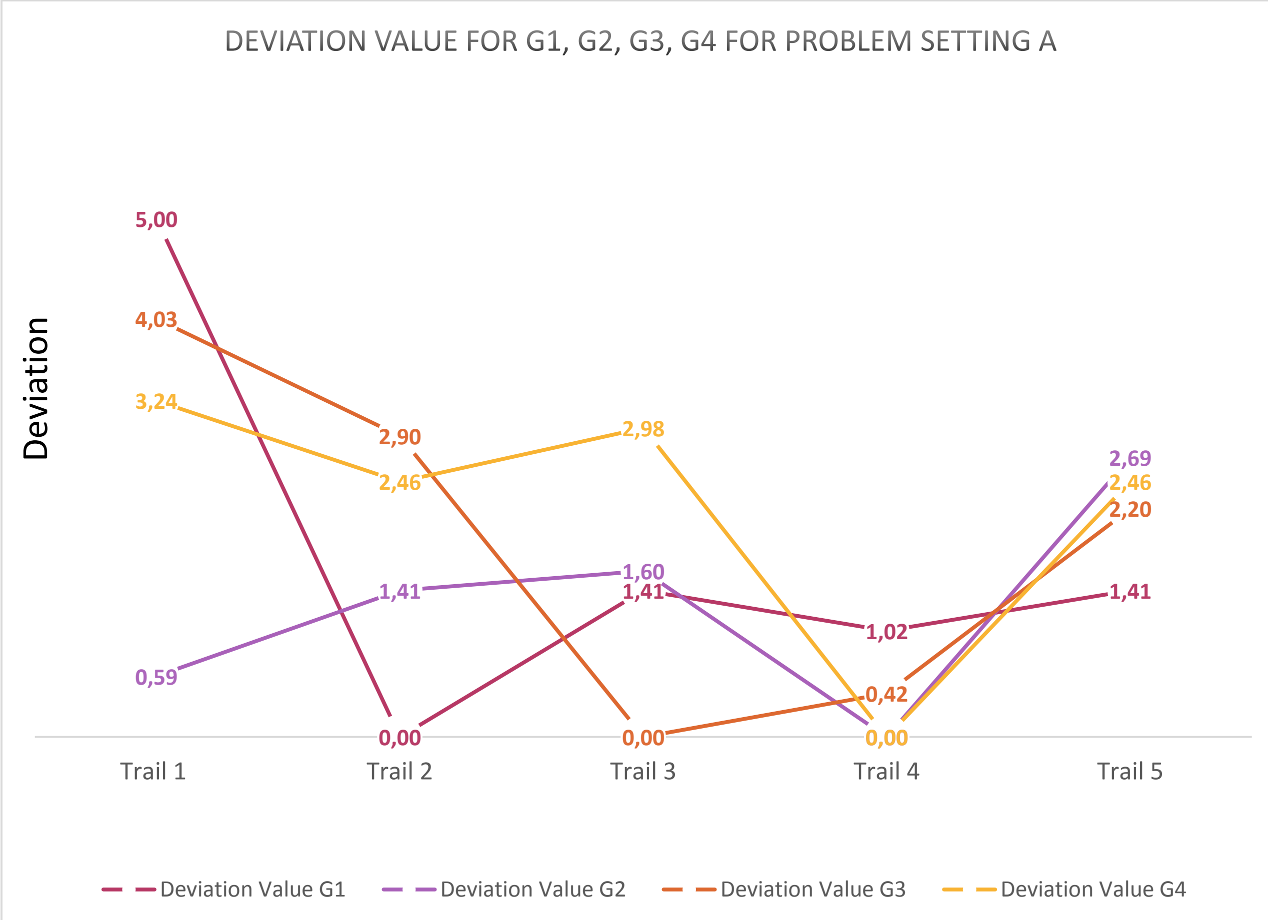

Fig. 6.2: Deviation value for G1, G2, G3, G4 for Problem Setting A

CONCLUSION

Earlier we saw that lot of job was tardy, so lost sale of these jobs as solving these problem by making a mathematical model and taking overtime decision and optimize profit we got that after solving through MATLAB no. of tardy job was very less and profit increase .As by using software we easily schedule cells & take overtime decision simultaneously. We also solve give data set using four strategies (GA1, GA2, GA3, and GA4) earlier we find that GA4 was best among all give the maximum value of objective function. Using these strategies we maximize our profit & also minimize tardy jobs. The observation outcome from GA approaches for scheduling in cellular manufacturing system was in term fitness value based main objective function. We have five different size segment for cellular manufacturing system we applied genetic algorithm for each segment to find fitness value here. We proposed Genetic algorithm with variation in crossover & mutation probability so overall four different parametrical(According change crossover & mutation strategies) used, for find the fitness value for five set of given data(due date, profit value etc).the outcome in terms of main fitness value for individual segment. For all observations are represented through graphical interpretation finally mean deviation for all five set of data with all four strategies(GA1,GA2,GA3,GA4),GA2 provides best Result for setting A, setting B, setting C for given data & for setting D, setting E GA4 shows best result

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