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Developing a Branch and Bound Algorithm for Cell Formation and Group Scheduling

Abstract- *Scheduling models for groups of parts have become more widely used in the industrial companies because of intensification of competition among them to get optimization in the delivery orders, reduce costs and increase quality. "Production scheduling is a meaning of verify a best or close to best achievement time plan for performing job, Production scheduling linked with the group technology applications is called Group Scheduling (GS). The objective of this research is to find optimum sequence of parts through cell formation and group scheduling. In this research, a lower bound for best possible Makespan is calculated by branch and bound algorithm and the best order of groups and parts generated. In this research, Branch and Bound algorithm was developed by the researcher to generate machine cell and part family then gathering groups to find sequence of groups as well as parts within it and calculate Makespan for problem . The developed algorithm have been tested by case study consist of four products processed on nine machine, the results from examining and testing of the developed algorithm is three machine cell and part family (MC-1,MC-2 and MC-3) as well as optimal Makespan for MCs is(344,152,122).*

Keywords: *Group Scheduling, Cell Formation*

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1. Introduction

Today manufacturing systems are increasing attention relative to competition and changeable conditions in the international market. Scheduling models for groups of parts have become more widely used in the industrial companies because of intensification of competition among them to get optimization in the delivery orders, reduce costs and increase quality [1]. Group technology can be defined as a disciplined approach in identifying parts attributes into different groups or families to take advantage of similar processing requirements. Analyzing of items attributes by looking for similarities between and among items to increase the efficiency and effectiveness managing items by taking advantage of the similarities" [2]. Cellular Manufacturing (CM) is one aspects of GT defined as a production system, in which similar parts are classified into part families and parts requiring a similar production process are grouped in distinct manufacturing cells. These similarities reduce cost effectiveness, setup times and improve flexibility of job shop manufacturing. The similar parts can be processed with similar jigs and fixtures in the mass production [3]. The major aim of group technology is the arrangement of part family and machine groups for the formation cells, where the parts in each cell are process with smallest move into other cells. The objective of research is to find group scheduling through a sequence of groups and jobs inside group, which minimizes several measures of performance. The measures of performance comprise Makespan, overall completion time, overall weighted flow time, amongst others. Makespan includes two dissimilar times estimate on a machine, the setup time used for the group on the machine .In this research, the group-scheduling problem in cellular manufacturing has been addressed. The makespan defined as the time at which the last job comes out of the system completely finished (the total spent time that is the time length from the beginning of the first operation of the first job to the finish of the last operation of the last job). When the cell formation performs, a group of jobs (parts) allocated to a cell shall be processed totally on a group of machines allocated to the like cell. The problem of calculating the sequence or order where the parts allocated to a cell would be processed in order to either minimize or maximize various measures of performance is generally. These measures of performance include overall completion time (Makespan), overall weighted flow time, and total weighted tardiness, amongst others. In This paper, the sections prepared as follow: section 2 contains an assessment of literature review and talk about the algorithms adopted for cell formation and group scheduling problem. Section3 Describes the proposed Branch and Bound algorithm for Cell Formation and Group Scheduling (CFGS). The developed algorithm is examined and tested by case study in section 4. In section 5, the computational results of branch and bound algorithm reported and results discussed. Finally, conclusion and future work were recorded.

2. Literature Survey

A popular of researchers studied machine cell formation and group scheduling by branch and bound algorithm. For machine cell formation, include**:**

Kusiak [4], addressed the scheduling problem of GT with parts and machines exception. The researcher developed dissimilar branching approaches using heuristic algorithm based on dissimilar branching schemes are developed. Three models have been developed of heuristic algorithm, where each algorithms model of them uses the cluster identification concept. The first model of heuristic algorithm considers GT problem through unconstraint. The second heuristic model solves the number of machines in each cell based on a constraint restricting. The third model of algorithm identifies exception of parts and machines by screening.

Cheng [5] used a branch and bound approach to resolve the clustering problem effectively, the proposed algorithm use optimal in addition to heuristic branch rules, while the optimal branching rule is not efficient for great problem; the heuristic branching rule considerably reduces the size of an enumeration hierarchy and provide an excellent result.

Chun et al. [6] evaluated a number of thumb rules for branch and bound algorithm to solve the cell formation problem. Furthermore, the author’s developed a new brunching rule to solve cell formation problem, which there are machines and parts exception.

Jamal et al. [7] introduced three models of branch and bound algorithms to resolve the GT problems. The primary model of algorithm use a binary branch scheme independent the descriptions supplied for the making decision. The second model is formed for the configuration of the cell formation problem. The anticipated hybrid genetic algorithm branch and bound algorithms are compared through some numerical examples. The final algorithm has a like configuration to the previous algorithm, except that it has the capability to remove duplicated nodes in branching hierarchy.

On other hand, a many of researches addressed GS problems, which described in the literature as follows:

Yoshida and Hitomi [8] presented a new method designed for optimal clarification of two machine flow-shop problems. They developed algorithm for minimize the overall completion time with alienate the setup times from machining times. This research considered an expanded of Johnson's work where the machines and job shop problem with setup times included is developed for scheduling optimization.

Yang and Liao [9] addressed a GT scheduling problem through 2 cells and internal cellular. The experiments investigation is to determine the operations sequence of all cells to minimize the mean flow time of jobs. Several parameters of case study are derived in the research work. These parameters combined together with a lower bound calculation to develop a branch-and-bound algorithm. Also A heuristic method is addressed to solve large sized of GT problems.*”*

Schaller [10] developed a new approach of lower bound of a branch and bound technique for group scheduling of job shop problem. This lower bound is more robust than the one proposed by Hitomi and Ham [11] proposed a two heuristics procedure which uses branch and bound approach in the first stage to develop a part family sequence and then in the second stage uses an interchange procedure to develop jobs within family sequence.

Logendran et al. [12] solved the GT scheduling problem to reduce the makespan time in a flexible job shop. In accordance with the previous researches finding obtain from solving the group-scheduling problem in a conventional flow shop. Combine heuristic LN-PT is used to determine the scheduling of GT problem in a flexible job shop. However, to use LN (or PT) to solve the level 1 problem and PT (or LN) to solve the level 2 problem in a flexible job shop should rightfully remain an open research question, which is intended to be addressed in future work.

Solimanpur et al. [13] show the scheduling of manufacturing cells considered where jobs be able to visit dissimilar machine cells. SVS is introduced to solve those problems. Intracell scheduling and intercell scheduling had been named. During intracell scheduling, the order of jobs inside manufacturing cells is estimated. During intercell scheduling the order of cells is gated.

Kanani et al. [14] introduced a GT scheduling problem for cellular manufacturing. Branch and bound (B&B) methods implanted using LINGO 8.0 software for different parts and cells relations to solve the GT scheduling problem that reduced the internal cellular moving, makespan time, sequence setup cost and tardiness.

3. The Developed Algorithm

With large number procedure of solution used as a method to solve the cell formations problems, this research uses branch and bound technique because it give results best solution in spite of the difficulty in the programmed.

The proposed methodology starts with each order to find machine cell and part family then create groups to find sequence of parts within and calculate Makespan for problem.

The proposed methodology for solution of various problems is divided into two phases (cell formation phase and group scheduling phases) as shown in Figure 1. In this research developed system has been implemented based on branch and bound algorithm called Cell Formation and Group Scheduling system (CFGS) for cellular manufacturing scheduling.

I. Branch and Bound for Cell Formation (BBCF)

The branch and bound is an algorithm for identifying clusters in a machine-part matrix. They developed many of heuristics to form machine cell and part families by rearrange the rows and columns of the machine-part incident matrix.

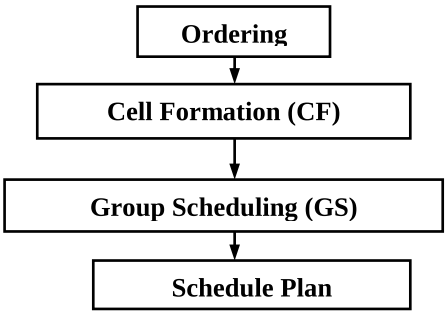

Figure 1: Proposed Methodology

<u>Steps of BBCF</u>

<u>Step1:</u> given an incident matrix A= $[a_{ij}]$. (Screening) Remove rows (columns) with larger number of ls than the threshold value for rows (columns).

<u>Step2:</u> Begin with the incidence matrix $[a_{ij}]$. Solve the GT problem represented with $[a_{ij}]$ (where i=5, j=4) using the CI algorithm.

$$[a_{ij}]=\begin{matrix}1&0&1&0\\0&1&0&1\\0&1&0&1\\0&1&0&1\\1&0&1&0\end{matrix}$$

<u>CI Algorithm</u>

<u>Step</u><u>1:</u> Specify iteration number k = 1.

<u>Step2:</u> Specify any row i of incidence matrix $[a_{ij}{}^{k})$ and indicate horizontal line h_i.

$$[a_{ij}]=\begin{matrix}1&0&1&0\\0&1&0&1\\0&1&0&1\\0&1&0&1\\1&0&1&0\end{matrix}$$

<u>Step 3:</u> For each entry of 1 crossed by the horizontal line h_i draw a vertical line v_j.

$$[a_{ij}]=\begin{matrix}1&0&1&0\\0&1&0&1\\0&1&0&1\\0&1&0&1\\1&0&1&0\end{matrix}$$

<u>Step 4:</u> For each entry of 1 crossed-once by a vertical line v_j draw a horizontal line h_k.

$$[a_{ij}]=\begin{matrix}1&0&1&0\\0&1&0&1\\0&1&0&1\\0&1&0&1\\1&0&1&0\end{matrix}$$

<u>Step 5:</u> Iterate two and three Steps until these no more crossed 1 entry in $[a_{ij}]^{(k)}$.All crossed-twice entries of 1 in $[a_{ij}]^{(k)}$ form machine cell MC-k and part family PF-k.

<u>Step 6:</u> The incidence matrix $[a_{ij}]^{(k)}$ should converted into $[a_{ij}]^{(k+1)}$ through eliminating rows and columns relative to all indicated lines from first steps until fourth step.

<u>Step 7:</u> If all elements equal to zero the matrix $[a_{ij}]^{(k+1)} = 0$ and stop; otherwise specify k = k + 1 and go to first step.

<u>Step 3:</u> For each submatrix identified by the CI algorithm: If the size of machine cell is satisfactory, store the matrix as a machine cell; otherwise, store it as a subproblem.

<u>Step 4:</u> If there is no subproblem to solve, stop; otherwise, arbitrarily select a subproblem to be solved.

<u>Step 5:</u> use the branching approach as follows.

<u>Step 6:</u> Select the child node to solve the corresponding GT problem with the CI algorithm, and go to first step. Steps of BBCF shown in Figure 2.

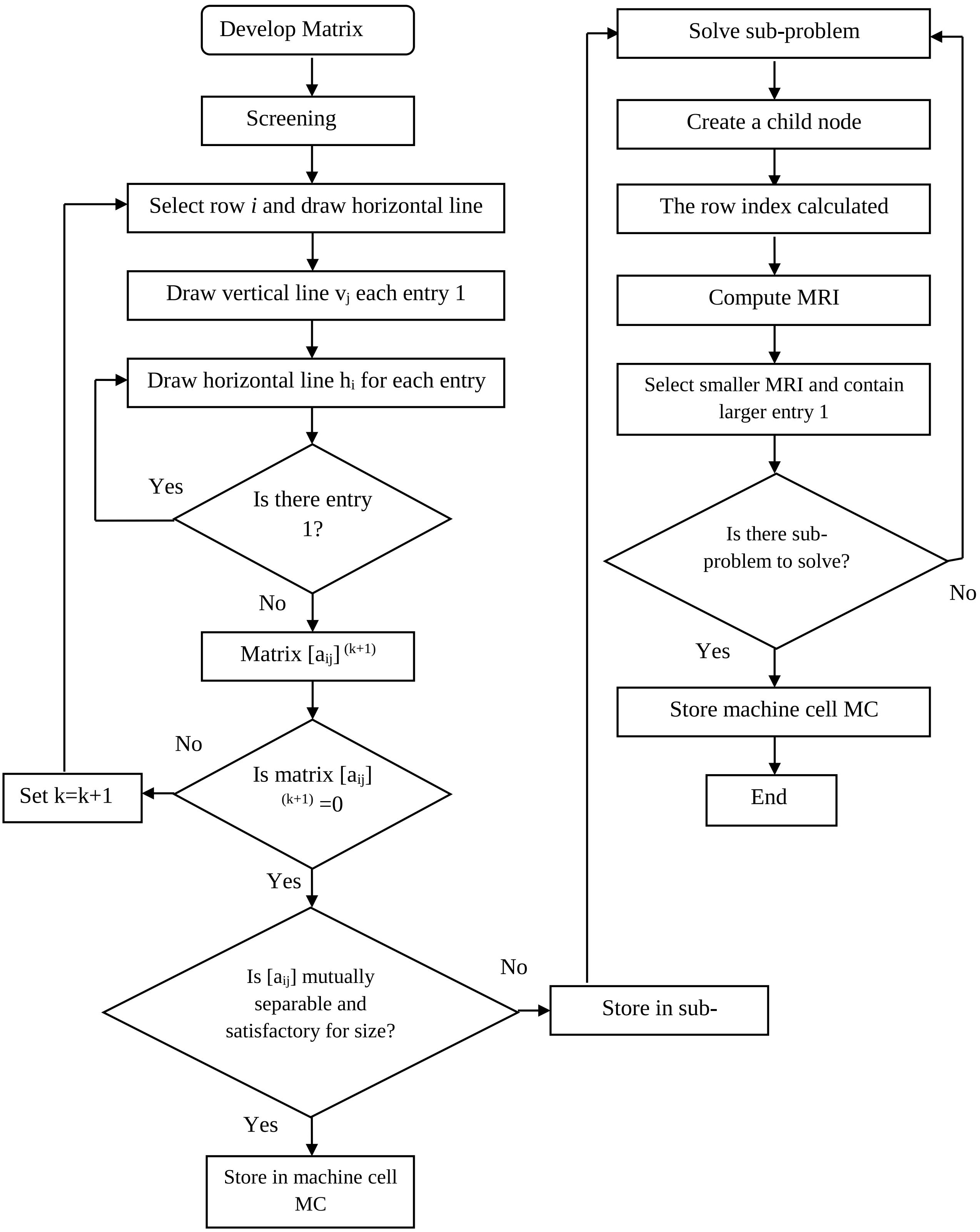

Figure 2: Flowchart of Branch and Bound Cell Formation Algorithm.

Branching Scheme

Branching is performed as follows:

- Generated the child nodes through eliminate only column at a time from the symmetric incidence matrix.
- Reading child node by removing *j*th column from the incidence matrix [a_{ij}].

II. Selection Scheme

For each row of the incidence matrix (child node) through applying the branching scheme, calculate a row index (the number of 1s in the corresponding row). The maximum value of the row index (MRI) is computed for each child node. The selection scheme is then applied as follows:

1. Selection of node that has the lowest MRI among the child nodes at the same level.
2. In the event of tie, apply the next MRIs until only one node is selected.
3. If one node cannot be selected based on the MRIs, select a node arbitrarily.
4. If identical columns exist, merge those columns and consider them as a single node (as if generated by removing several identical columns).

For each part j of the corresponding submatrix, define the bottleneck measure BM_j as follow:

$$BM_j = \sum_{j=1}^{p} aij \quad (1)$$

Where:

(i=1, 2,…, m)

M is equal number of machine

(j=1, 2,…., p)

P is equal number of parts

III. Group scheduling by Branch and Bound (BBGS)

With the large number procedure of solution used as a method to solve the cell formations problems, this research uses branch and bound technique because it give results best solution in spite of the difficulty in the programmed, Branch and Bound algorithm will be used for group scheduling (BBGS) although it requires require many computational efforts to find an optimal solution for large-sized problems

IV. Steps of BBGS

The branch and bound algorithm shown in Figure 3 used for determining the best possible Group scheduling below the condition of the least makespan.

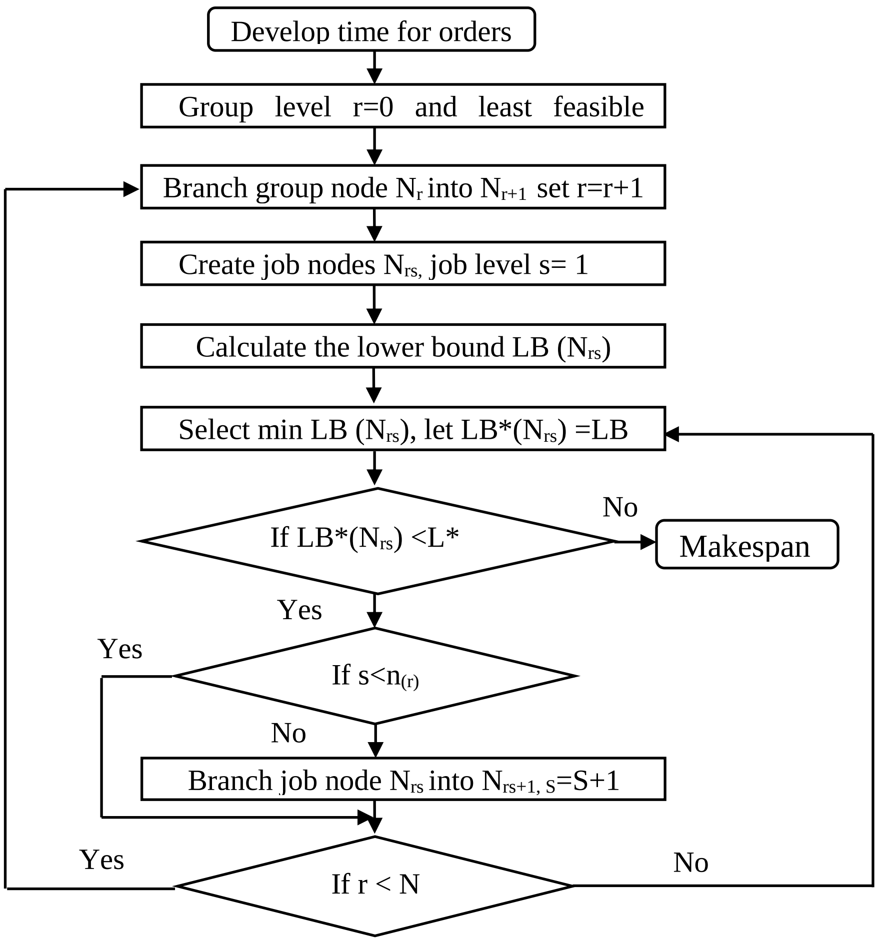

Figure 3: Flowchart Branch and Bound for Group Scheduling Algorithn

4. Sample Problem

Examining and testing the capabilities of the developed CFGS system are carried out through a simple example. The original data are shown in Table 1 as matrix of (4) products, (9) machines by (39) parts, that first product form of 9 parts, second product form of 12 parts, third product form of 8 parts, and four product form of 10 parts. Branch and Bound algorithm used for cell formation, we obtain the best solution shown in Table 2.

After algorithm is applied, three machine cell and part family (MC-1, MC-2 and MC-3) observed and parts (9 in prodcut1, 10 in product 2, 1 and 2 in product 3, 4 in product 4) are bottleneck parts. In order to start group scheduling stage, the parts from different products that operate by similar machines are grouped as shown in Table 3. In second stage, Branch and Bound algorithm for group scheduling is applied with three groups (MC-1, MC-2 and MC-3) form of four, three and two stages (machine).

Table 1: Incident Matrix of Case study.

	Product1									Product2												Product3								Product4									
J/M	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10
M1	1			1								1			1						1			1	1						1			1			1		1
M2		1			1		1			1	1					1		1	1	1		1				1		1		1	1	1	1						
M3			1			1		1	1				1	1			1		1				1				1		1						1	1		1	
M4	1			1								1			1						1			1	1									1			1		1
M5		1			1		1		1	1	1					1		1	1	1		1				1		1		1	1	1	1						
M6		1			1		1		1	1	1					1		1		1		1				1		1		1	1	1	1						
M7	1			1					1			1			1						1			1	1									1			1		1
M8			1			1		1	1				1	1			1		1			1	1				1		1		1		1		1	1		1	
M9	1			1								1			1				1		1			1	1									1			1		1

Table 2: Final part-machine incidence matrix.

	Product1									Product2												Product3								Product4									
7	1	4	2	5	7	3	6	8	9	3	6	12	1	2	7	9	11	4	5	8	10	3	4	5	7	2	6	8	1	5	8	10	1	3	6	7	9	2	4
M1	1	1								1	1	1										1	1							1	1	1						1	
M4	1	1								1	1	1										1	1							1	1	1							
M7	1	1							1	1	1	1										1	1							1	1	1							
M9	1	1								1	1	1									1	1	1							1	1	1							
M2			1	1	1								1	1	1	1	1				1			1	1				1				1	1				1	1
M5			1	1	1				1				1	1	1	1	1				1			1	1				1				1	1				1	1
M6			1	1	1				1				1	1	1	1	1							1	1				1				1	1				1	1
M3						1	1	1	1									1	1	1	1					1	1	1							1	1	1		
M8						1	1	1	1									1	1	1	1					1	1	1	1						1	1	1	1	1

In second stage, Branch and Bound algorithm for group scheduling is applied with three groups (MC-1, MC-2 and MC-3) form of four, three and two stages (machine). The setup and processing time of each part and each machine is given in Table 4. The optimal group schedule is determined by using branch and bound algorithm as show in Table 5.

Table 3: Grouping Part for each MC.

MC-1												
	G_1		**G_2**			**G_3**		**G_4**				
J/M	1	4	3	6	12	3	4	5	8	10		
M1	1	1	1	1	1	1	1	1	1	1		
M4	1	1	1	1	1	1	1	1	1	1		
M7	1	1	1	1	1	1	1	1	1	1		
M9	1	1	1	1	1	1	1	1	1	1		
MC-2												
	G_1			**G_2**					**G_3**		**G_4**	
J/M	2	5	7	1	2	7	9	11	5	7	1	3
M2	1	1	1	1	1	1	1	1	1	1	1	1
M5	1	1	1	1	1	1	1	1	1	1	1	1
M6	1	1	1	1	1	1	1	1	1	1	1	1
MC-3												
	G_1			**G_2**			**G_3**			**G_4**		
J/M	3	6	8	4	5	8	2	6	8	6	7	9
M3	1	1	1	1	1	1	1	1	1	1	1	1
M8	1	1	1	1	1	1	1	1	1	1	1	1

Table 4: Setup time and processing time for each MCs and PFs.

MC-1																
	G_1			**G_2**				**G_3**			**G_4**					
Job(part)		J_1	J_4		J_3	J_6	J_{12}		J_3	J_4		J_5	J_8	J_{10}		
Machine	S_1	P_{11}	P_{12}	S_2	P_{21}	P_{22}	P_{23}	S_3	P_{31}	P_{32}	S_4	P_{41}	P_{42}	P_{43}		
M1	5	18	16	3	15	18	19	4	15	19	4	20	16	17		
M4	4	13	15	3	15	17	19	3	25	15	5	15	17	19		
M7	3	10	6	4	7	10	8	2	6	8	3	9	10	5		
M9	4	10	10	4	50	50	60	5	25	28	4	17	20	21		
MC-2																
	G_1				**G_2**						**G_3**			**G_4**		
Job(part)		J_2	J_5	J_7		J_1	J_2	J_7	J_9	J_{11}		J_5	J_7		J_1	J_3
Machine	S_1	P_{11}	P_{12}	P_{13}	S_2	P_{21}	P_{22}	P_{23}	P_{24}	P_{25}	S_3	P_{31}	P_{32}	S_4	P_{41}	P_{42}
M2	2	15	8	4	5	14	5	9	5	7	3	10	11	6	12	8
M5	4	6	13	10	2	10	7	11	14	10	8	9	7	2	15	14
M6	7	12	5	12	8	2	9	20	12	4	5	3	5	4	6	7
MC-3																
	G_1				**G_2**				**G_3**				**G_4**			
Job(part)		J_3	J_6	J_8		J_4	J_5	J_8		J_2	J_6	J_8		J_6	J_7	J_9
Machine	S_{1J}	P_{11}	P_{12}	P_{13}	S_2	P_{21}	P_{22}	P_{23}	S_3	P_{31}	P_{32}	P_{33}	S_4	P_{41}	P_{42}	P_{43}
M3	4	3	16	4	3	7	10	8	4	6	8	14	5	4	10	7
M8	7	8	4	5	6	4	9	15	3	4	5	12	3	5	9	10

Table 5: Makespan and sequence by CFGS

Group	Sequence	Makespan
MC-1	$G_2(J_{21}$-J_{22}-$J_{23}) – G_1(J_{12}$-$J_{11}) – G_3(J_{31}$-$J_{32}) – G_4(J_{43}$-J_{42}-$J_{41})$	344
MC-2	$G_1(J_{13}$-J_{12}-$J_{11}) – G_3(J_{31}$-$J_{32}) – G_2(J_{24}$-J_{22}-J_{25}-J_{23}-$J_{21})$-$G_4(J_{42}$-$J_{41})$	152
MC-3	$G_1(J_{11}$-J_{12}-$J_{13})$ - $G_2(J_{21}$-J_{23}-$J_{22}) – G_4(J_{41}$-J_{43}-$J_{42})$ - $G_3(J_{31}$-J_{33}-$J_{32})$	122

5. Results and Discussion

The results from case study when it is examined and tested by CFGS as follow; Firstly, by using Branch and Bound algorithm for cell formation obtained three machine cell (MC-1,MC-2,MC-3) and four part families (PF-1,PF-2,PF-3,) for each product where:

MC-1{M1, M4, M7, M9}
MC-2{M2, M5, M6}
MC-3{M3, M8}

as well as that parts (9 from product1; 10 from product2; 1 from product3; 2,4 from product4) are bottleneck parts which are dealt with: it can be subcontracted, it can be machined in one machine cell and transfer to the other machine cell by a material handling carrier, it can be machined in an efficient capacity. Secondly; once cell formation stage is completed and similar machine is grouped group scheduling stage is started to determine sequence and calculate Makespan, by using Branch and Bound algorithm obtained as following results:

MC-1{G_2 (J_{21}-J_{22}-J_{23}) – G_1 (J_{12}-J_{11}) – G_3 (J_{31}-J_{32}) – G_4 (J_{43}-J_{42}-J_{41})},
MC-2 {G_1 (J_{13}-J_{13}-J_{11}) – G_3 (J_{31}-J_{32}) – G_2 (J_{24}-J_{22}-J_{25}-J_{23}-J_{21}) – G_4 (J_{42}-J_{41})},
MC-3 {G_1 (J_{11}-J_{12}-J_{13}) - G_2 (J_{21}-J_{23}-J_{22}) – G_4 (J_{41}-J_{43}-J_{42}) – G_3 (J_{31}-J_{33}-J_{32})}, and
The makespan is {344,152,122} respectively.
The makespan for each group schedule is simply obtained by depicting the Gantt chart, as shown in Figure 4, 5 and 6. The bounding procedure is a process of calculating the lower bound on solution of the subproblem represented by each job-node. Compared branch and bound algorithm and LN/PT for case study and other problem, the obtained results represent that branch and bound for group scheduling has ability to decrease the makespan as compared to LN–PT method. The advantages of CFGS system can be outlined as follows:

1- CFGS discover bottleneck parts and drifted away from problem of the first steps to solve.
2- CFGS is effectiveness in reduction makespan as compared to LN–PT method.
3- CFGS system linking between two stage cell formation and group scheduling at the same time.

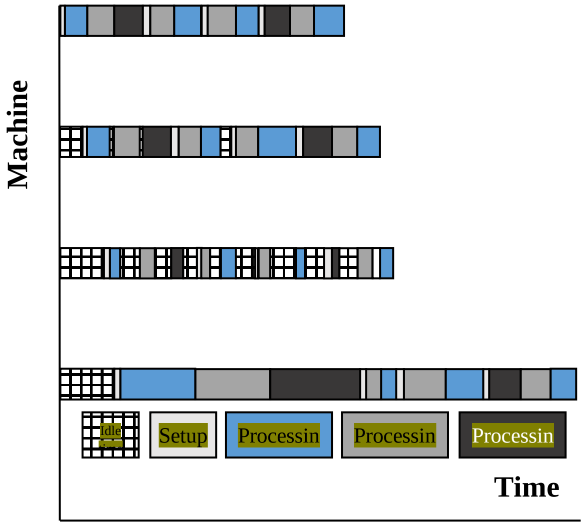

Figure 4: Makespan for MC-1 by Gantt chart.

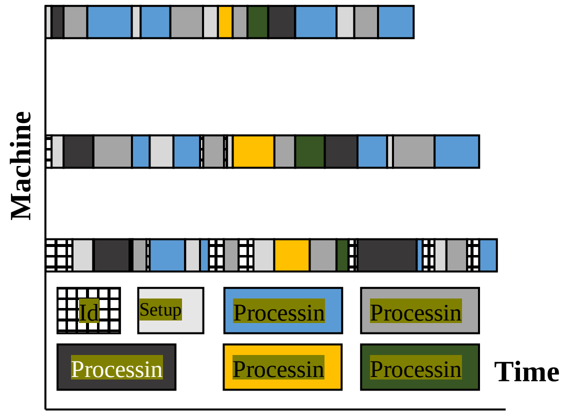

Figure 5: Makespan for MC-2 by Gantt chart.

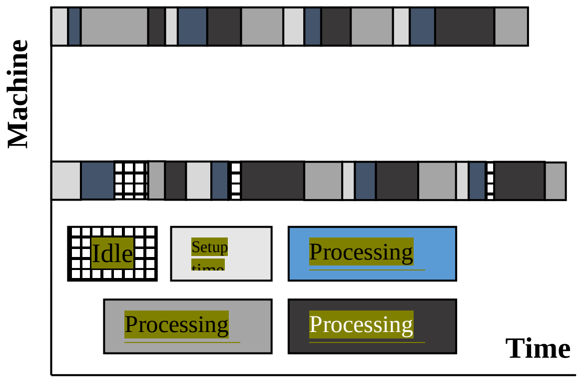

Figure 6: Makespan for MC-3 by Gantt chart.

6. Conclusions

Using Branch and bound technique and heuristic rules together provide ability to handle cell formation problems with bottleneck machines and bottleneck parts. Branch and bound technique has been proposed in this research for solving group-scheduling problems in cellular manufacturing. It's developed for group scheduling of common form and can be used to determine the best job and the best group order for any form of problems and completion time (makespan) is minimized. The proposed system has proved to be flexible and easy to use, so that it can be used for any product. It is easier and far simpler to calculate, compared to other similar heuristic algorithms such as (LN/PT, LN/LN, etc).

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