INTEGRATING SIMULATION AND OPTIMIZATION TO SCHEDULE BATCHES IN PARALLEL HYBRID FLOW SHOP

Saravanan .R[1], Raju .R[2], Ramasamy .M[3]

[1]Research Scholar, Department of Industrial Engineering, Anna University, Chennai.

[2]Department of Industrial Engineering, Anna University, Chennai.

[3]Department of Management, Madha Engineering College, Chennai.

Email : [1] rsarravanan@yahoo.com

Abstract

Nowadays manufacturing organizations produces their products in high variety with low volume to meet the requirements of variety of customers by using existing resources. Scheduling is the task of allocation of resources over time to process jobs. The importance of good scheduling strategies in production environments is obvious. The need to respond to market demands quickly and to run plants efficiently gives rise to complex scheduling problems in all but the simplest production environments. This research is motivated by an operation scheduling for an automobile spare manufacturing plant. The Problem complexity is, male and female components of assemblies flow for processing in two parallel hybrid flow shop with in separable nature, the pre processing time is stochastic nature, storage space between the work centers are limited. The objective is not only to minimize the completion time but also optimize the resource utilization and average queue length. Simulation modeling and analysis used to analyze the behavior of this complex production environment and an algorithm suggested for scheduling any number of batch. In the case study, the algorithm outperforms and yielded best solution and the suggested schedule reduced completion time drastically.

Keywords: Hybrid flow shop, scheduling, SR algorithm, Simulation, Queue length, SPT rule.

I. INTRODUCTION

Traditional manufacturing systems have taken many general forms. In increasingly complex manufacturing environments, more complex manufacturing systems have been created in order to address such factors as limited capacity and complicated process plans. For example, the semiconductor industry uses re-entrant flow lines, in which multiple machines may exist at each stage and jobs revisit previous stages many times in a cyclic manner. The printed circuit board and automobile industries make use of flow lines with multiple machines at some stages and allow jobs to skip stages (1). Some precision industries used to process components of assembly simultaneously in different manufacturing line. The components may use some stages as common in their individual flow sequence. The scheduling objective in such industries may vary. Due date related criteria may be important. The makespan criterion is made use of many researchers and has been selected for this research. Scheduling to minimize makespan in parallel hybrid flow shop in which male and female jobs flow sequence are not the same but all male jobs follow same sequence vice versa are the focus of this paper. This kind of manufacturing environment introduces new difficulties in hybrid flow shop scheduling.

II. PROBLEM DEFINITION

To begin, we define the scope of the problem considered in this research. The term Hybrid flow shop (HFS) in the literature synonyms like flow shop with multiple processors, flow shop with parallel machines or flexible flow line are likewise common characteristic a generalization of the standard flow shop where at least one stage comprises more than one identical machine. The HFS consists of $S > 1$ stages where a stage $s, 1 < s < S$, comprises $Ms < 1$ identical parallel machines. A given set J of $J > 1$ jobs has to be processed on the machines of this flow shop where each job consists of S operations with processing times Pjs, $1< j <J$, $1<s<S$. All jobs follow the same unidirectional flow pattern through the shop where an operation has to be processed on one of the parallel machines of the corresponding stage. Between the processing of two subsequent operations of the same job, it can be buffered in a queue in front of the corresponding stage. At the beginning, all jobs are queued in front of the first stage or arrive there at their release times. But the parallel flexible flow line (Figure 1) is one in which dependent jobs such us components of assembly flow simultaneously over parallel HFS and they sent to assembly shop for assembling. These HFS are inseparable because the both kind of jobs need to processing at some common stages. The notation in the Figure- 1 is HFSij is used to describe the Hybrid flow shop 'HFS' number 'i' and its stage ' j'

The general assumptions are:

- The number of jobs, their release times, due dates, and processing times are known and fixed;
- All male jobs follow the same stage sequence; and all female jobs follow the same sequence;
- No job may be cancelled before completion, no operation may be split or pre-empted;

- No two operations of the same job may be processed simultaneously;

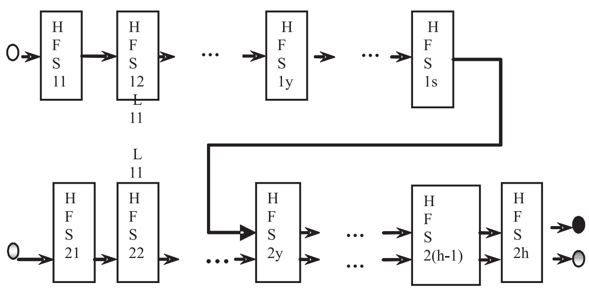

Fig. 1. Parallel Hybrid flow shop with common stages

- Setup time is independent of the job sequence and therefore is considered part of the processing time;
- All machines of the same stage are identical;
- No machine may process more than one job at a time;
- Machines may remain idle;
- In-process inventory is allowed.

A. The Mathematical model:

Jm – the male job ***Jm*** **(*Jm*=1,2,…..,*e*)** of assembly type ***g*** **(*g* = 1,2,.., *x*)** where ***e*** total number of jobs to be processed/ lot size; Where ***x*** is total number assembly types /lots are to be scheduled. Similarly ***Jf*** – the female job ***Jf*** **(*Jf*=1,2,…..,*e*)** of assembly type ***g***. $Jm_g, Jf_g \in Jg$;

$(P_{i/y})_{Jmg}$ – Processing times of male job ***Jm*** of assembly type ***g*** at ***i*** th stage in HFS1 or ***y*** th stage in HFS2 ***i*** **(*i* = 1,2,…s)** , **y (y = 1,2, …, h)** where **s** and **h** are the total number of stages in HFS1 and HFS2 respectively. Similarly $(P_{y/i})_{Jfg}$ is the Processing times of female job ***Jf*** of assembly type ***g*** at ***y*** th stage in HFS2 or ***i*** th stage in HFS1

m_i and m_y - the number of parallel identical processor available in stage ***i*** of HFS1 and y of HFS2 respectively.

T_m and T_f – Total number of time units in scheduling male jobs and female jobs respectively

T – Maximum total time units in scheduling in either male or female jobs

$(C_{i/y})_{Jmg}$ – completion time of male job ***Jm*** of type ***g*** at the stage ***i*** or ***y***. It is a time point $(C_{i/y})_{Jmg} = t_m$ means that the operation completes at the end of the time unit t_m. Similarly

$(C_{y/i})_{Jfg}$ – completion time of female job ***Jf*** of type ***g*** at the stage ***y*** or ***i***. It is a time point $(C_{y/i})_{Jfg} = t_f$ means that the operation completes at the end of the time unit t_f.

Decision variables:

$(\delta_{i/y})_{Jmg}\, t_m$ = { 1 if Jm_g is processed at the stage ***i*** or ***y*** in the time unit t_m 0 other wise }

$(\delta_{y/i})_{Jfg}\, t_f$ = {1 if Jf_g is processed at the stage ***i*** or y in the time unit t_f 0 other wise }

With the above notation the parallel HFS scheduling problem under the consideration can be formulated as follows.

Note that $(C_k)_{Jmg}$ in the model final completion time of the male job ***Jm*** of type ***g***, C_k after processed require **k** stages. (Including both flow line) in other words it is completion time of a male job of type ***g*** similarly $(C_u)_{Jfg}$ completion time of a female job of type ***g***, and C_u means time taken after processed require **u** stages. (Including both flow line)

$$\textbf{Minimize} \sum_{g=1}^{x} \sum_{Jm=1}^{e} (C_k)_{Jmg} \qquad [1]$$

Objective 1 is to minimize sum of completion time of all male jobs of all types

$$\textbf{Minimize} \sum_{g=1}^{x} \sum_{Jf=1}^{e} (C_u)_{Jfg} \qquad [2]$$

Objective 2 is to minimize sum of completion time of all female jobs of all types

$$\text{Minimize } \{\max\{\sum_{g=1}^{x} \sum_{Jm=1}^{e} (C_k)_{Jmg}, \sum_{g=1}^{x} \sum_{Jf=1}^{e} (C_u)_{Jfg}\}\} \qquad [3]$$

Objective 3 is to minimize the maximum of sum of completion time of all female and male jobs of all types

subjected to

$$(C_{i/y})_{Jmg} \le (C_{i/y})_{Jmg+1} - (P_{i/y})_{Jmg},$$
$$i\ (i = 1,2,\ldots s);\quad y\ (y = 1,2,\ldots, h);$$
$$g\ (g = 1,2,.., x);\quad Jm_g \in Jg; \qquad [4]$$

$$(C_{y/i})_{Jfg} \le (C_{y/i})_{Jfg+1} - (P_{y/i})_{Jfg},$$
$$i\ (i = 1,2,\ldots s);\quad y\ (y = 1,2,\ldots, h);$$
$$g\ (g = 1,2,.., x);\quad Jf_g \in Jg; \qquad [5]$$

$$\sum_{t_m=1}^{T_m} (\delta_{i/y})_{Jmg}\, t_m = (P_{i/y})_{Jmg},$$

$$i\ (i = 1,2,\ldots s);\quad y\ (y = 1,2,\ldots, h);$$
$$g\ (g = 1,2,.., x);\quad Jm_g \in Jg;\quad t_m = 1,2,\ldots,T_m; \qquad [6]$$

$$\sum_{t_f=1}^{T_f} (\delta_{y/i})_{J\,fg}\, t_f = (P_{y/i})_{Jfg},$$

i (i = 1,2,…s); y (y = 1,2, …, h);
g (g = 1,2,.., x); Jf_gє Jg; t_f = 1,2,…,T_f; [7]

$$t_m \ast (\delta_{i/y})_{Jmg}\, t_m \le (C_{i/y})_{Jmg}\,,$$

i (i = 1,2,…s); y (y = 1,2, …, h); g (g = 1,2,.., x);
Jm_gє Jg; t_m = 1,2,…,T_m ; [8]

$$t_f \ast (\delta_{y/i})_{J\,fg}\, t_f \le (C_{y/i})_{Jfg},$$

i (i = 1,2,…s); y (y = 1,2, …, h); g (g = 1,2,.., x);
Jf_gє Jg; t_f = 1,2,…,T_f ; [9]

$$(C_{i/y})_{Jmg} - (P_{i/y})_{Jmg} + 1 \le t_m + T_m (1 - (\delta_{i/y})_{Jmg}\, t_m,)$$

i (i = 1,2,…s); (y = 1,2, …, h); g (g = 1,2,.., x);
Jm_gє Jg; t_m = 1,2,…,T_m; [10]

$$(C_{y/i})_{Jfg} - (P_{y/i})_{Jfg} + 1 \le t_f + T_f (1 - (\delta_{y/i})_{J\,fg}\, t_f\,),$$

i (i = 1,2,…s); y (y = 1,2, …, h); g (g = 1,2,.., x);
Jf_gє Jg; t_f = 1,2,…,T_f ; [11]

$$\sum_{Jm_g=1}^{e} (\delta_{i/y})_{Jmg}\, t_m \le m_i \text{ and } m_y\,, \quad i\ (i = 1,2,\ldots,s);$$

y (y = 1,2, …, h); t_m = 1,2,…,T_m ; [12]

$$\sum_{Jf_g=1}^{e} (\delta_{y/i})_{J\,fg}\, t_f \le m_y \text{ and } m_i\,,\quad i\ (i = 1,2,\ldots s);$$

y (y = 1,2, …, h); t_f = 1,2,…,T_f ; [13]

$(\delta_{i/y})_{Jmg}\, t_m$ є {0,1}, i (i = 1,2,…s);
y (y = 1,2, …, h); t_m = 1,2,…,T_m; Jm_gє Jg; [14]

$(\delta_{y/i})_{J\,fg}\, t_f$ є {0,1} , i (i = 1,2,…s);
y (y = 1,2, …, h); t_f = 1,2,…,T_f; Jf_gє Jg; [15]

$(C_{i/y})_{Jmg}$ є { 1,2,…,T_m}, i (i = 1,2,…s);
y (y = 1,2, …, h); Jm_gє Jg; [16]

$(C_{y/i})_{Jfg}$ є {1,2,…,T_f}, i (i = 1,2,…s);
y (y = 1,2, …, h); Jf_gє Jg; [17]

In the above formulation, the objective is to be determining a schedule that minimizes the total completion time of assembly parts i.e. both male jobs and female jobs while satisfying all the constraints as listed above. We choose this our objective because it concentrates on the manufacturing lead time, a company can achieve reduced work-in- process inventory, avoid delayed lot submission (tardy job reduction) and improved customer services, etc.

Constraints [4] and [5] represent operation precedence among the stages for a job and ensure that an operation cannot be started until the operation of the same job at its preceding stage is finished. Constrains [6] – [11] define the time intervals for which a job is processed on a machine at a stage. Constraints [12] and [13] indicate that all these machine requirements are satisfied with the number of available machines at that time. Constraints [14] – [17] define values ranges of the variables.

III. LITERATURE REVIEW

After 50 years of research in the field of flow shop scheduling problems the scientific community still observes a noticeable gap between the theory and the practice of scheduling. Some of the research highlighted here are those attempts made towards filling the gap. Rubén Ruiz et al propose a formulation along with a mixed integer modelization and some heuristics for a new class of HFS scheduling problem of n jobs on m stages where at each stage a known number of unrelated machines and jobs might skip stages (2). Xianpeng Wang and Lixin Tang suggested a tabu search heuristic for the HFS scheduling with finite intermediate buffers (3). Hua Xuan establishes an integer programming model and proposes a batch decoupling based Lagrangian relaxation algorithm for scheduling a HFS with batch production at the last stage (4). A heuristic algorithm and a mixed integer program are proposed by Ling-Huey Su for a two-stage HFS with limited waiting time constraints (5). Similar to the scheduling problem being addressed in this study, simulation has been used widely to improve factory performance. Many researchers have evaluated the effectiveness of various scheduling rules. Karzata investigates a variety of scheduling strategies for their effectiveness: such as the first-come-first served strategy and the shortest-time-first strategy (6).

This research also made such attempt by integrating simulation and optimization for solving a complex problem.

IV. CASE STUDY

*A Problem Background***:** The organization produces automobile spare part namely vibration dampers which are one of the leading suppliers to Ashok Leyland, Tata Motors, Cummins, Ford, G.M. and Hindustan Motors. The company faces more tardy jobs in Rubber dampers which has three varieties in each. Each of the rubber dampers consists of two components namely pulley and hub. The pulley and hub are processed separate HFS and are assembled in the assembly shop with some bought out spare. The organization takes 44 days including pre-processing (estimated based on active machine hours) to complete the orders. Customer commitment for not meeting the due date is transport charges. The penalty is become high when transportation by air way. Pulley and hub jobs are processed in flexible flow lines in such a way that pulley components are processed in maximum five stages and hub components in four stages. They finished at common stages. So that both HFS s are to be optimized simultaneously else assembly will get delayed. The HFS1 consists of 3 stages such as stage1 has two identical lathes, stage2 has two identical CNC lathes and stage 3 has one NH lathe. The HFS2 has 4 stages such as stage1 has two identical C20 lathes, stage2 has two identical CNC lathes, stage 3 has one drilling machine and stage 4 consists of one broaching machine. Stage 3 &4 are used to complete the processing of both pulley and hub jobs. So these two stages are called as common stages. The pre processing probabilistic parameters [mean, spread] in minutes furnished in table 1 for pulley & hub type. The processing times at various stages with the sequence of operations of pulley and hub jobs are shown in table 2. For this specific application of this multi lot, dynamic, parallel HFS scheduling problem the objective function can be personalized as follows:

The maximum number of jobs in each lot (e) =1000; Total types of job to be processed (x) =3;

Number of parallel processor available in each stages of HFS1 ($\mathbf{m}_i$) are:

$m_{i=1}=2$; $m_{i=2}=2$ and $m_{i=3}=1$; (refer figure 2).

Number of parallel processor available in each stages of HFS2 ($\mathbf{m}_y$) are:

$m_{y=1}=2$; $m_{y=2}=2$; $m_{y=3}=1$; and $m_{y=4}=1$;

Hence the objective functions is minimize

$$\textbf{Minimize} \quad \sum_{g=1}^{3} \sum_{Jm=1}^{1000} (C_5)_{Jmg} \qquad [18]$$

Objective 1 is to minimize sum of completion time of all male jobs of all types

Table 1. Stochastic preprocessing times' parameters

Job	g_i	Max	Min	Process Parameters
Pulley (male)	1	10	15	[12.5 , 2.5]
	2	15	20	[17.5 , 2.5]
	3	17	22	[19.5 , 2.5]
Hub (female)	1	23	29	[26 , 3]
	2	8	14	[11 , 3]
	3	7	10	[8.5 , 1.5]

Table 2. Processing time and sequence of operations in parallel HFS

Job		HFS1				HFS2			
	g_i	HFS11	HFS12	HFS13		HFS21	HFS22	HFS23	HFS24
Pulley (male)	1	4.7	3.4	3.5		0	0	2.0	4.8
	2	4.3	3	2		0	0	5	6.5
	3	4.5	1.5	2.5		0	0	4	5.5
Hub (female)	1	0	0	0		3.5	2.5	5.2	4.3
	2	0	0	0		4.5	2.3	3.5	4.8
	3	0	0	0		3	4.8	4.5	5.2

Table 3. Trail wise Lots and Optimum Completion Time

No. of Type of lots in simultaneous processing	Trail	Sequence	Type 1		Type 2		Type 3		Order Completion Time in Minutes	Optimum Completion Time in Minutes
			Male	Female	Male	Female	Male	Female		
1	1	1 - 2 - 3	12533	25914	43446	36806	63025	51970	63023	63023
1	2	1 - 2 - 3	12533	25914	30065	36806	49642	45330	49642	49642
2	3	2 & 3 - 1	34543	47924	21433	17104	22010	14487	47924	
2		3 & 1 - 2	15614	25914	43446	36806	19577	12268	43446	43446
2		1 & 2 - 3	16329	25914	19018	14809	45491	34438	45491	
2	4	2 & 3 - 1	33966	40401	21433	17104	22010	14487	40401	
2		3 & 1 - 2	15614	25914	33146	36806	19577	12268	36806	
2		1 & 2 - 3	16329	25914	19018	14809	35906	23333	35906	35906
3	5	1 , 2 & 3	25054	29140	29997	29986	23066	19157	29997	29997

Table 4. Machine Utilization and Queue Status while Processing Single, Double & Triple Combination

MACHINE / PROCESSOR	Processing Single Type of Lots			Processing Two types of lots jointly			Processing three types of lots jointly		
	Machine Utilization	Average Length	Average job waits	Machine Utilization	Average Length	Average job waits	Machine Utilization	Average Length	Average job waits
Lathe1	15%	0.00	0.00	23%	0.00	0.00	31%	0.01	0.01
Lathe2	0%			7%			14%		
CNC 1 1stLine	9%	0.00	0.00	15%	0.00	0.00	21%	0.00	0.00
CNC 2 1stLine	0%			2%			6%		
NH	9%	0.00	0.00	18%	0.01	0.13	27%	0.04	0.41
C20 II Lathe	12%	0.00	0.00	19%	0.00	0.00	26%	0.01	0.06
C20 I Lathe	0%			5%			11%		
CNC 1 2Line	11%	0.00	0.00	17%	0.00	0.00	23%	0.00	0.00
CNC 2 2Line	0%			4%			9%		
Drilling	21%	0.03	0.48	42%	0.48	53.13	62%	97.40	730.52
Broaching	24%	0.04	0.56	48%	0.56	923.10	72%	173.56	1301.70

$$\textbf{Minimize} \quad \sum_{g=1}^{3} \sum_{Jf=1}^{1000} (C_4)_{Jfg} \qquad [19]$$

Objective 2 is to minimize sum of completion time of all female jobs of all types

$$\text{Minimize} \ \{ \max \{ \sum_{g=1}^{3} \sum_{Jm=1}^{1000} (C_5)_{Jmg} , \sum_{g=1}^{3} \sum_{Jf=1}^{1000} (C_4)_{Jfg} \} \} \qquad [20]$$

Objective 3 is to minimize the maximum of sum of completion time of all female and male jobs of all types

B. The Simulation Model:

The model aims to simplify the complex natured hybrid flow shop scheduling problem. The simulation model with the constraints listed above by using Extend v6 simulation software was done for conducting experiments with real time effect. The simulation is used here to collect measure of performances for each manufacturing strategies set, such as completion time of male and female components lots of each type, mean lead time, variance, standard deviation, queue status, and machine utilization. The queues are first in first out. The modified list-scheduling algorithms were used here. In this algorithms, when a machine (at a stage) becomes available, an operation with the highest priority among those that can be processed on the machine at that moment is assigned to and processed on the machine as first come first serve. Also, when an operation becomes available and there are two or more machines available for the operation at that moment, we select a machine with the highest priority (from a machine selection rule). Priorities of available operations are which has latest finish time as priority rule which controls the jobs unless otherwise use the parallel processor if the primary processor engaged.

C. Trial Runs:

The order consists of three types of pulley and hub lots. In order to optimize maximum completion time of all lot, the various possible random trial runs were tested. They are:

1. Each type of pulley and hub processing may be done one by one where next type processing starts after the completion of pulley and hub jobs processing of existing one. That is processing sequence of types 1-2–3 or 2 –3-1 or 3 –1-2
2. Each type of pulley and hub processing may be done one by one where next type processing of pulley or hub starts after the completion of either pulley or hub jobs processing of existing one. The processing sequence may be types 1-2–3 or 2–3-1 or 3–1-2
3. Any two types of pulley and hub processing may be done simultaneously where next type processing starts after the completion of all pulleys and hubs jobs processing of existing. The possible processing sequence are 1&2-3 , 2&3-1, and 3&1-2
4. Any two types of pulley and hub processing may be done simultaneously where next type's pulley or hub processing starts after any one of pulley and hub jobs processing completed. The possible processing sequence are 1&2-3 , 2&3-1, and 3&1-2
5. All three types of pulley and hub processing may be done simultaneously.

Mathematically order completion time computation and optimum value selection can be expressed as

For trial 1:

$$\max\left\{\sum_{Jm=1}^{1000}(C_5)_{Jm1},\ \sum_{Jf=1}^{1000}(C_4)_{Jf1}\right\} + \max\left\{\sum_{Jm=1}^{1000}(C_5)_{Jm2},\ \sum_{Jf=1}^{1000}(C_4)_{Jf2}\right\} + \max\left\{\sum_{Jm=1}^{1000}(C_5)_{Jm3},\ \sum_{Jf=1}^{1000}(C_4)_{Jf3}\right\} \quad [21]$$

For trial 2:

$$\max\left\{\left[\sum_{Jm=1}^{1000}(C_5)_{Jm1} + \sum_{Jm=1}^{1000}(C_5)_{Jm2} + \sum_{Jm=1}^{1000}(C_5)_{Jm3},\ \left[\sum_{Jf=1}^{1000}(C_4)_{Jf1} + \sum_{Jf=1}^{1000}(C_4)_{Jf2} + \sum_{Jf=1}^{1000}(C_4)_{Jf3}\right]\right\} \quad [22]$$

For trial 3:

(a) Maximum completion time of schedule 2&3 - 1 Cm_{31} is:

$$\max\left\{\left[\sum_{Jm=1}^{1000}(C_5)_{Jm2},\ \sum_{Jm=1}^{1000}(C_5)_{Jm3}\right],\right.$$

(Combined 2 types of pulley jobs)

$$\left.\left[\sum_{Jf=1}^{1000}(C_2)_{Jf2},\ \sum_{Jf=1}^{1000}(C_4)_{Jf3}\right]\right\} +$$

(Combined 2 types of hub jobs)

$$\max\left\{\sum_{Jm=1}^{1000}(C_3)_{Jm1},\ \sum_{Jf=1}^{1000}(C_4)_{Jf1}\right\} \quad [23]$$

(Single type pulley & hub lots)

(b) Maximum completion time for this schedule

1&3 -2 Cm_{32} is:

$$\max\left\{\left[\sum_{Jm=1}^{1000}(C_5)_{Jm1},\ \sum_{Jm=1}^{1000}(C_5)_{Jm3}\right],\right.$$

(Combined 2 types of pulley jobs)

$$\left.\left[\sum_{Jf=1}^{1000}(C_2)_{Jf1},\ \sum_{Jf=1}^{1000}(C_4)_{Jf3}\right]\right\} +$$

(Combined 2 types of hub jobs)

$$\max\left\{\sum_{Jm=1}^{1000}(C_3)_{Jm2},\ \sum_{Jf=1}^{1000}(C_4)_{Jf2}\right\} \quad [24]$$

(Single type pulley & hub lot)

(c) Maximum completion time for this schedule

1&2 - 3 Cm_{33} is:

$$\max\left\{\left[\sum_{Jm=1}^{1000}(C_5)_{Jm1},\ \sum_{Jm=1}^{1000}(C_5)_{Jm2}\right],\right.$$

(Combined 2 types of pulley jobs)

$$\left.\left[\sum_{Jf=1}^{1000}(C_2)_{Jf1},\ \sum_{Jf=1}^{1000}(C_4)_{Jf2}\right]\right\} +$$

(Combined 2 types of hub lots)

$$\max\left\{\sum_{Jm=1}^{1000}(C_3)_{Jm3},\ \sum_{Jf=1}^{1000}(C_4)_{Jf3}\right\} \quad [25]$$

(Single type pulley & hub lots)

Hence the optimum sequence is one which has minimum completion time mathematically Minimum $\{Cm_{31}, Cm_{32}, Cm_{33}\}$ [26]

For trial 4:

(a) Maximum completion time for this schedule 2&3 -1 say Cm_{41} is

$$\text{Max}\ \{\min\{\sum_{Jm=1}^{1000}(C_5)_{Jm2},\ \sum_{Jm=1}^{1000}(C_5)_{Jm3}\} +$$

(Combined 2 types of pulley)

$$\sum_{Jm=1}^{1000}(C_3)_{Jm1},\quad \min\{\sum_{Jf=1}^{1000}(C_2)_{Jf2},\ \sum_{Jf=1}^{1000}(C_4)_{Jf3}\}$$

(Single lot pulley) (Combined 2 types of hub)

$$+\sum_{Jf=1}^{1000}(C_4)_{Jf1}\ \} \quad [27]$$

(Single type hub lot)

(b) Maximum completion time for this schedule

1&3 -2 Cm_{42} is:

$$\text{Max}\ \{\min\{\sum_{Jm=1}^{1000}(C_5)_{Jm1},\ \sum_{Jm=1}^{1000}(C_5)_{Jm3}\} +$$

(Combined 2 types of pulley)

$$\sum_{Jm=1}^{1000}(C_3)_{Jm2},\quad \min\{\sum_{Jf=1}^{1000}(C_2)_{Jf1},\ \sum_{Jf=1}^{1000}(C_4)_{Jf3}\}$$

(Single lot pulley) (Combined 2 types of hub)

$$+\sum_{Jf=1}^{1000}(C_4)_{Jf2}\ \} \quad [28]$$

(Single type hub lot)

(c) Maximum completion time for this schedule

1&2 -3 Cm_{43} is

$$\text{Max}\ \{\min\{\sum_{Jm=1}^{1000}(C_5)_{Jm1},\ \sum_{Jm=1}^{1000}(C_5)_{Jm2}\} +$$

(Combined 2 types of pulley)

$$\sum_{Jm=1}^{1000}(C_3)_{Jm3},\quad \min\{\sum_{Jf=1}^{1000}(C_2)_{Jf1},\ \sum_{Jf=1}^{1000}(C_4)_{Jf2}\}$$

(Single lot pulley) (Combined 2 types of hub)

$$+\sum_{Jf=1}^{1000}(C_4)_{Jf3}\ \} \quad [29]$$

(Single type hub lot)

Hence the optimum sequence is one which has minimum completion time mathematically

minimum $\{Cm_{41}, Cm_{42}, Cm_{43}\}$ [30]

For trial 5:

Maximum completion time $(Cm)_{c3}$ in the schedule 1,2&3 combine is

$$\max\{\sum_{Jm=1}^{1000}(C_3)_{Jm1},\ \sum_{Jm=1}^{1000}(C_5)_{Jm2},\ \sum_{Jm=1}^{1000}(C_5)_{Jm3},$$

$$\sum_{Jf=1}^{1000}(C_4)_{Jf1},\ \sum_{Jf=1}^{1000}(C_2)_{Jf2},\ \sum_{Jf=1}^{1000}(C_4)_{Jf3}\ \} \quad [31]$$

After made the necessary modification in the simulation model for each trail, the completion time was taken for individual lot and the order completion time, optimum completion time were computed as per the mathematical relations listed above. The results were tabulated in table 3. This was noted that trail 1 completes order processing optimally by 63023 minutes, trail 2 by 49642 minutes, trail 3 by 43446 minutes, trail 4 by 35906 minutes and trail 5 by 29997 minutes. The simultaneous processing of number of batches (types of pulley and hub) will reduces the completion time significantly like the way it increases the machine utilization percentage and increases the average queue length. Based on the statistics the manufacturer can decide how many batches can combine for processing simultaneously. The table 4 illustrates average queue status average job waits in front of each machine center and average machine utilization for each machine while processing single type, combined two types and combined three types.

V. HEURISTIC ALGORITHM

If the number of lot increases number of the trail also increases. The computation time and effort also high for n job types batches scheduling. The heuristic algorithm suggested for scheduling such case to find optimal scheduling and sequencing with less effort and optimally. Cheng et al considered food manufacturing environment as single-machine scheduling of multi-operation jobs without missing any of the operations with the aim of minimizing the total completion time(7). Similarly in this case the two parallel hybrid flow shop consider as two separate dependent single machine scheduling problem. Convway et al presented the proof as when one schedule an 1/n/ mean flow time problem, the mean flow time is minimized by the sequencing the job order of non decreasing processing time i.e SPT (8). So here SPT sequencing used for minimizing the maximum completion time of male and female jobs there by reducing overall completion time. Hence the heuristic algorithm provides optimal sequencing for any number of variety lots processing in parallel hybrid flow shop scheduling problems.

Step 1: consider the completion time of each job lot from the single type lot trial as the processing time of that type of male and female lot. let t_{mg} and t_{fg} are the completion times of male and female job lot of type ***g*** respectively. Mathematically

$$t_{mg} = \sum_{Jm=1}^{e} (C_5)_{Jmg}, \qquad t_{fg} = \sum_{Jf=1}^{e} (C_4)_{Jfg}$$

Step2: The job processing sequence may be arranged as the male jobs lot according to non decreasing order of total processing time. Consider initial sequence S_m and there must exist a pair of adjacent jobs, ***i*** and ***j,*** their processing times are t_{mi} and t_{mj} respectively. The jobs to be rearrange in SPT sequence

{

1. Begin with initial sequence S_m.
2. Locate pair of adjacent jobs i and j with j following i such that tmi > tm j
3. Interchange the jobs i and j in sequence.
4. Return to step 2 iteratively, improving the performance measures each time, until eventually the SPT sequence Sm' is constructed.

}

This sequence will satisfy the objective function [1] and Arrange female jobs lot also according to non decreasing order of total processing time. Consider initial sequence S_f and there must exist a pair of adjacent jobs, ***i*** and ***j***, their total processing times are t_{fi} and t_{fj} respectively. The jobs to be rearranged in SPT sequence

{

1. Begin with initial sequence Sf.
2. Locate pair of adjacent jobs i and j with j following i such that tfi > tf j
3. Interchange the jobs i and j in sequence.
4. Return to step 2 iteratively, improving the performance measures each time, until eventually the LPT sequence S_f' is constructed.

}

This sequence will satisfy the objective function [2]

Step 3: The optimum sequence for male and female job lots separately from step 2. How many types to be assigned for simultaneous processing may be decided by the manufacturer i.e. combine 1 or 2 ... or x types. The lot indexing is illustrated with GANT chat (figure 2). The GANT chart shows that how to index lots in processing which minimize total completion time i.e. satisfy equation [3]. For illustration the optimum sequence for male which is obtained from step 2 is M1, M2, …,Mn and for female job lots as F1, F2, …,Fn and the notation used as: **t** for time, **M** for male component lots and **F** for female component lots. In the Gant chart, The M1 and M2 are assigned for simultaneous processing then the lot M3 dispatched for processing after the earliest completion by M1 and then M4 after M2. Now M3 and M4 lot get processing simultaneously. Here M5 is dispatched after the earliest completion by M4 and so on. This same way the job lots have to be assigned for the female lots also.

Step 4. The maximum completion time $\mathbf{C_j}$ is completion of last lot either male / female in the sequence of indexing which can be computed as for single type processing using equation [22] and for two types case equations like [27], [28], and [29]. The GANT chart show this by vertical dotted line.

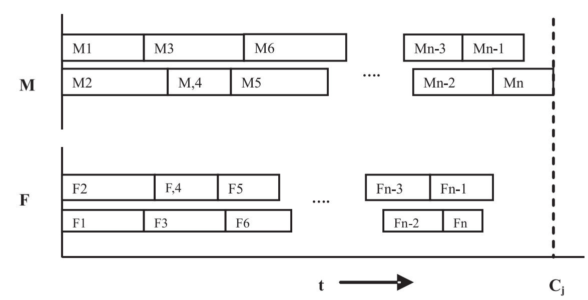

Fig. 2. Gant chart- job indexing & total completion time

A.. Numerical Example:

Step 1: Let the processing time of male job lots from the trial 1 are

t_{m1} = 12533 minutes; t_{m2} = 17532 minutes;
t_{m3} = 19577 minutes;
and for female job lots are
t_{f1} = 25914 minutes; t_{f2} = 10892 minutes;
t_{f3} = 8524 minutes;

Step 2: S_m = {1,2,3}= {12533, 17532, 19577 }

S_f = {1,2,3}= {25914, 10892, 08524 }

S_m' = {1,2,3}= {12533, 17532, 19577 }

S_f' = {3,2,1}= {25914, 10892, 08524 }

Step 3 : The optimum sequence is male and female lots can be write as M-F such as 1-3; 2-2; 3-1; Maximum completion time in minutes for this schedule 1&2 -3 in Pulley and 3&2 -1 in pulley lots obtained from simulation run for single type simultaneous processing of male and female lots (M-F): 1-3; 2-2; 3-1;

Run 1 t_{m1} = 12533 minutes; t_{f3} = 8528 minutes;

Run 2 t_{m2} = 17532 minutes; t_{f2} = 10892 minutes;

Run 3 t_{m3} = 19577 minutes; t_{f1} = 25914 minutes;

Step3 (According trail 2)

max { (12533 +17532 + 19577) ,

(8528 + 10892 + 25914) }

= max {49642 , 45334 }= 49642

which equal to the value obtained in schedule 1-1 ; 2-2; 3-3;

Thus it is proved that the schedule based on SPT sequence of each lot completion time, is optimal for n job scheduling problem.

VI. CONCLUSION

The new kind of complex problem found from industry named Parallel HFS scheduling Problem. General mathematical model developed and the same was applied for a specific case well in this article. The simulation modeling was done using Extend V6 software for computing key values for optimization by doing computer simulation. Various possible trail runs were conducted using simulation model and the optimum schedule was tabulated in table 3 and the same was submitted to the industry. The authors extended the problem for n assembly types batches scheduling problem. But the trial method is not feasible to obtain such type of problem due to increases the number of trial required linearly with respect to the number of types to be scheduled. So a heuristic algorithm suggested that integrates simulation and optimization to find the optimum schedule which satisfies all the objectives and the same was illustrated with numerical example. Simulation model used in this method is to get the basic processing time of each type which helps to obtain the optimal schedule. In the numerical example section schedule obtained from the algorithm is validated and proved as optimal.

REFERENCES

[1] Agnetis, A., Pacifici, A., Rossi, F., Lucertini, M., Nicoletti, S. and Nicolò, F., 1997, Scheduling of flexible flow lines in an automobile assembly plant. European Journal of Operational Research. 97 (2), pp. 348-362.

[2] Rubén Ruiz, Funda Sivrikaya Şerifoğlu, Thijs Urlings., 2008, Modeling realistic hybrid flexible flow shop scheduling problems. Computers & Operations Research, Vol. 35(4), pp. 1151-1175.

[3] Xianpeng Wang, Lixin Tang ., 2009, A tabu search heuristic for the hybrid flow shop scheduling with finite intermediate buffers'. Computers & Operations Research, Vol. 36, Issue 3, pp. 907-918.

[4] Hua Xuan, Lixin Tang ., 2007, Scheduling a hybrid flow shop with batch production at the last stage'. Computers & Operations Research, Volume 34, Issue 9, pp. 2718-2733.

[5] Ling-Huey Su ., 2003, A hybrid two-stage flow shop with limited waiting time constraints' Computers & Industrial Engineering, Volume 44, Issue 3, pp. 409-424.

[6] Karzata, H., 2000, A comparative analysis of scheduling policies in a distributed system using simulation. International Journal of Simulation, vol 1(1/2), pp. 12–20.

[7] Cheng ,T.C.E., Ng C.T., Yuan J.J., 2008, Single-machine scheduling of multi-operation jobs without missing operations to minimize the total completion time'. European Journal of Operational Research, Volume 191(2), pp. 320-331.

[8] Richard W.Conway, Willium L. Maxwell, and Louis W. Miller, 1967, Theory of Scheduling, addition Wesley Publishing Company, pp. 26-28.

R. saravanan is a post graduate in Industrial Engineering and a graduate in Mechanical Engineering from the Thiagarajar College of Engineering, Madurai. At present he is an Assistant Professor at the Madha Engineering College, Chennai.