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A HEURISTIC FOR BATCH SCHEDULING WITH UNIFORM AND NON UNIFORM LOT SIZES IN TWO STAGE HYBRID FLOWSHOP

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ABSTRACT

Recent manufacturing strategy is changing the configuration of manufacturing environment by adding standby or rental facilities in parallel to meet the delivery schedule. The hybrid flow shop often encounter in such cases. Scope of this work is to minimize the makespan by optimal group schedule. This problem is motivated by demand of an automobile spare manufacturing environment. The customized mathematical model furnished for $m = 2$, $M^{(1)} = 2$, $M^{(2)} = 1$, $k = 6$ *batch scheduling problem. The two stage hybrid flow shop is usually NP hard in nature so a heuristic based approach preferred. The developed heuristic is applicable for both lot streaming as well as group scheduling. Ten lot streaming cases considered and 296 schedules generated and tested for validation. The mathematical model used to develop the simulation model in Extend v6 to verify and validate the heuristic solutions. The uniform and variable lot size cases were considered. Even though obtaining the optimal schedule by using suggested heuristic the uniform lot size is* *recommended by considering uniform utilization of critical machine and minimizing its buffer.*

Keywords: Hybrid flowshop; Mathematical modelling; Lot streaming; Heuristics; Simulation, Group scheduling, Critical Machine.

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1. INTRODUCTION

The present manufacturing scenario handles the high variety of jobs with low volume due to the customization of products. To meet the customer demands, jobs were grouped and manufactured based on operational requirement. Grouping the jobs with similar operations and they were processed through the multistage production system. The Hybrid Flow Shop (HFS) environment characterized by production flow shop with single/multiple parallel machines added in each production stage, As HFS problems NP hard in nature they can solve polynomially with some special properties and precedence relationships or heuristic method [1]. Generally the single objective of any scheduling problem needs a comprehensive knowledge on preference factor of each objective; to overcome this drawback the multi objective optimization was used [3]. Makespan alone will not decide the effectiveness of the hybrid flowshop; a best way of optimization in the HFS environment is only by multi-objective. [4] optimized the two stage assembly scheduling problem ($m = 2$, $M^{(1)} = m$, $M^{(2)} = n$) by minimizing the sum of weighted completion times with better resource utilization. [5,6] insisted the critical machines consideration on scheduling and its significant effects. Vivek et al [7] used weighted scheduling approach to minimize the idle time at critical machine in permutation flowshop and discussed the importance and effectiveness of critical machine based scheduling. [8] suggested the simulation is a an effective tool to analyse the queue status at bottleneck or critical machines and solved dynamic parallel non uniform flow hybrid flowshop problem using simulation. Franklin Issac et al. [9], suggested simulation based heuristic for multi stage HFS group scheduling problem. [10] suggested heuristic and developed a mathematical model to solve ($m = 2$, $M^{(1)} = 1$, $M^{(2)} = 2$) HFS problem. [11] suggested a mathematical model for solving lot-streaming HFS batch scheduling problem in which they considered priority rule with shortest weighting time and concurrent arrival of jobs. Vivek et al [12], developed mathematical model and suggested heuristic for 2 stage HFS ($m = 2$, $M^{(1)} = 2$, $M^{(2)} = 1$) lot streaming problem. The simulation is used for lot sizing and validation of the heuristic solutions (group schedules) for similar and variable lot sizes. [13] reported that lot streaming received less attention from the researchers, simulation is an best tool to investigate the effectiveness of lot streaming with sequencing rules, lot sizing, scheduling scenarios with respect to the in-process inventory status, machine utilization. [14], stated that large lot-size problems effectively solved with the help of heuristics and meta-heuristics and the authors proposed a rolling-horizon heuristic to solve such a problem. Tsubone et al. [15], proposed two heuristics for HFS lot streaming problem to find the best number of sub-lot in-group scheduling. The authors considered an equal-sub-lots; Jobs provided as sub-lot which has similar processing time as well as order of processing on the given hybrid flow production environment. This research focuses two stage HFS ($m = 2$, $M^{(1)} = 2$, $M^{(2)} = 1$, $k=6$) lot streaming problems with uniform and variable lot sizes cases. The objective is to minimize makespan as well as lot streaming strategy.

2. MATHEMATICAL MODEL

The specific mathematic model developed and presented in this section for the two stage HFS (m = 2, $M^{(1)}$ = 2, $M^{(2)}$ = 1, k=6) lot streaming problem.

2.1. Assumptions

The following assumptions are made

i) All the jobs are unidirectional in flow.
ii) Preemption is not permitted
iii) Job setup times are included in the processing time.
iv) Unlimited intermittent storage capacity for work in process is assumed initially.
v) All the jobs are available at zero time on the first stage.
vi) There is no breakdown, *i.e.,* the machines are available continuously.
vii) Splitting of the individual sub - lot is not permitted for forming the lot. But sub lots may be grouped to form lots with all possible ways.
viii) The next lot will consider for processing after the completion of the last job of the last lot at all the stages.
ix) The lot size may be uniform / non-uniform.

2.2. Parameters

J_i = the job J_i (J_i =1, 2, ..., n) in i^{th} (i = 1, 2, …, k) sub-lot $J_i \in J$,

k = Total number of sub-lots

n = Total number of jobs in the sub-lot. i.e., sub-lot size,

J = Total number of jobs to be scheduled,

Gs = Group schedule

$(P_m)_{Ji}$ = Processing times of job Ji at m^{th} stage, m = 1, 2

$M^{(1)}$ = 2 one parallel machine at first stage hence two machine at stage 1,

$M^{(2)}$ = 1 one machine at second Stage

T = Total number of time units in scheduling jobs,

$(C_m)_{Ji}$ = Completion time of job J of sub-lot i at the stage m,

t time unit

2.3. Mathematical Model

The lots are formed by combining of sub-lots or sub lot alone as per lot streaming strategy; lot streaming strategy is chosen with the available sub-lots. Lot completion time is the completion time of the last job of the lot. Makespan is the **c**ompletion time of the last job of the last lot. The objective of the problem minimizing makespan. The objective function is a mathematically written as

$$\text{Minimize} \quad \sum_{i=1}^{k} \sum_{J_i=1}^{n} (C_2)_{Ji} \qquad 1$$

Subject to

$$(C_2)_{Ji} \le (C_2)_{Ji} + 1 - (P_2)_{Ji} \qquad J_i \ (J_i=1,2,\ldots,n);\ J_i \in J; \qquad 2$$

$$\sum_{t=1}^{T_m}(\delta_2)_{Ji}t=(P_2)_{Ji} \quad ; t = 1,2,\ldots,T; \qquad 3$$

$$t*(\delta_2)_{Ji}t\le(C_2)_{Ji} \qquad 4$$

$$(C_2)_{Ji}-(P_2)_{Ji}+1\le t+T(1-(\delta_2)_{Ji}t) \qquad 5$$

$$\sum_{Ji=1}^{n}(\delta_2)_{J_i}t\le M^{(s)} \quad ; \qquad M^{(1)}=1, M^{(2)}=2 \qquad 6$$

$$(\delta_2)_{Ji}t\in\{0.1\} \qquad 7$$

$$(C_2)_{Ji}\in\{1,2,\ldots,T\} \qquad 8$$

In this mathematical model, the objective is to find the optimal group scheduling that minimizes the makespan with the stated constraints in the equation (2) to the equation (8). The equation (2) is precedence constraint, *i.e.*, an operation cannot start until the completion required operation in the preceding stage. The (3) – (5) defines the time intervals for which a job processing on a machine at a stage. The equation (6) defines the machine constraint at each stage *i.e.*, machine requirements. The equation (7) & (8) provides the time range of the variables.

2.4. Makespan Computation

Mathematical representation of computation of makespan for a sample group schedule $\{L_1(J_1\&J_2) - L_2(J_3\&J_4) - L_3(J_5\&J_6)\}$ is

$$C_j = max\left\{\sum_{j_i=1}^{200}(C_2)_{j_1},\ \sum_{j_i=1}^{200}(C_2)_{j_2}\right\} + max\left\{\sum_{j_i=1}^{200}(C_2)_{j_3},\ \sum_{j_i=1}^{200}(C_2)_{j_4}\right\} + max\left\{\sum_{j_i=1}^{200}(C_2)_{j_5},\ \sum_{j_i=1}^{200}(C_2)_{j_6}\right\}$$

Mathematical representation of computation of makespan for a sample group schedule $\{L_1(J_1,J_2\&J_3) - L_2(J_4, J_5\&J_6)\}$ is

$$C_j = max\left\{\sum_{j_i=1}^{200}(C_2)_{j_1},\ \sum_{j_i=1}^{200}(C_2)_{j_2},\sum_{j_i=1}^{200}(C_2)_{j_3}\right\} + max\left\{\sum_{j_i=1}^{200}(C_2)_{j_4},\sum_{j_i=1}^{200}(C_2)_{j_5},\ \sum_{j_i=1}^{200}(C_2)_{j_6}\right\}$$

3. HEURISTIC

Step 1: Lot is formed by single sub-lot or combining sub-lots *i.e.*, the lot size varies from single sub-lot to k sub-lots. The total processing of job per lot in all lots (**C_l**), mathematically it can be written as

$$C_l=\sum_{i=1}^{k}\ \sum_{m=1}^{2}P_{m\,ji}\forall T;C_l\in T$$

Step 2: Compute the mean processing time (**m_p**) where n_l is number of sub-lots and (N_l) is desired number of lot to be formed.

$$m_p = \frac{C_l}{N_l n_l}$$

Step 4: Sub-lot formation

a. To form the lot, the sub-lots to be allocated as per lot streaming strategy in such a way that the total processing time of job per sub lot for all sub lots in all lots is nearly equal to other lots as per lot streaming strategy.
b. Compute the deviation (d) of lot processing time from mp. The deviation may be either positive or negative or zero.
c. Compute the algebraic sum of those deviations.
   i) If the algebraic sum of those deviations (∑d) is zero; it is best lot streaming. The group schedule gives an optimal solution.
   ii) If the algebraic sum of those deviations (∑d) is nearly equal to zero or very minimum, it is a better lot streaming; the group scheduling gives near optimal solution.
   iii) If the algebraic sum of those deviations (∑d) is more, balance the deviations by reallocating the sub-lot; go to step-4a.

The iteration to be continued; until to reach the condition of step 4c (i) or 4c (ii).

4. SIMULATION MODEL

Simulation is best tool to conduct real time experiments and examine the queue status flow status machine status validation of priority rules etc [8]. The goal of the research is to minimize the makespan and optimize the lot streaming strategy. So the simulation modelling was done in Extend v6 based on the mathematical model developed and included all the constraints. The model is verified and validated properly. The model is used here to find the lot completion times, queue status, machine status. The FIFO queue system is preferred.

5. REAL WORLD PROBLEM CASE STUDY

The manufacturer is leading supplier of automobile spares. The supplies the spares with minimum order quantity say 200 numbers per spare item. As they required similar kind of operations the spare items can be mixed for processing. Such mixing possibilities is in proposal level this research is aimed for optimizing such mixing and reducing the makespan significantly through lot streaming. The spares are having common due date due to despatch to customer through air. Even though many spare varieties the six kinds of spares has constant demand. So in this research such six spares are considered. As per availability of machines the existing configuration can be classified as ($m = 2$, $M^{(1)} = 2$, $M^{(2)} = 1$) hybrid flowshop.

5.1. Problem Description

In the Two stage Hybrid flowshop ***($m = 2$)***, the first stage has two parallel identical machines ***($M^{(1)} = 2$)*** and the second stage has only one machine ***($M^{(2)} = 1$).*** There is six spares ***$i(i=1,2,\ldots,6)$*** sub-zntity (***$J_i=1, 2,..,200$***). The processing times ***(P_{mji})*** presented in table 1. Hence the objective function can be rewritten as

$$\text{Minimize} \sum_{i=1}^{6}\sum_{J_i=1}^{200}(C_2)_{Ji}$$

Table 1 Processing time (minutes) of jobs in stages

Sub-Lot.	$M^{(1)}$	$M^{(2)}$
J_1	5.42	1.50
J_2	2.70	4.94
J_3	2.86	2.90
J_4	4.22	3.94
J_5	5.86	1.94
J_6	4.50	3.66

5.2. Computational Experiments and validation of Heuristic

Table 2 Makespan of simulated solution for various lot streaming strategies

LSS Index	Lot Streaming Strategy (LSS)	N_l	Total Gs simulated	Best Schedule	Optimal Make span
1	6	1	1	(j_1, j_2, j_3, j_4, j_5 & j_6)	3781
2	5 & 1	2	6	(j_1, j_2, j_4, j_5 & j_6) - (j_3)	3784
3	4 & 2	2	15	(j_1,j_2,j_3 & j_6) - (j_4 & j_5)	3783
4	3 & 3	2	10	(j_1, j_3 & j_6) - (j_2, j_4 & j_5)	3782
5	2, 2 & 2	3	15	(j_1 & j_6)- (j_2 & j_3) - (j_4 & j_5)	3788
6	3, 2 & 1	3	60	(j_1,j_3 & j_6) - (j_4 & j_5) - (j_2)	3786
7	4, 1 & 1	3	15	(j_1,j_2,j_3 & j_5) - (j_4) - (j_6)	3983
8	2, 2, 1 & 1	4	15	(j_1& j_4) - (j_5&j_6) - (j_2) - (j_3)	3791
9	3, 1, 1 & 1	4	60	(j_1,j_2&j_3) - (j_4) - (j_5) - (j_6)	3990
10	2, 1, 1, 1 & 1	5	15	(j_1& j_3) - (j_2) - (j_4) - (j_5) - (j_6)	3993
11	Conventional	6	1	(j_1)-(j_3) - (j_2) - (j_4) - (j_5) - (j_6)	4238

Table 3 Heuristic based Lot formation and its deviation of mean processing time

LSS Index	Best Schedule	Mean (m_p)	Deveation from mean (d)						∑d
1	(j_1, j_2, j_3, j_4, j_5 & j_6)	44.44	0						0.00
2	(j_1, j_2, j_4, j_5 & j_6) - (j_3)	22.22	16.5	-16.5					0.00
3	(j_1,j_2,j_3 & j_6) - (j_4 & j_5)	22.22	6.26	-6.26					0.00
4	(j_1, j_3 & j_6) - (j_2, j_4 & j_5)	22.22	-1.38	1.38					0.00
5	(j_1 & j_6)- (j_2 & j_3) - (j_4 & j_5)	14.81	0.27	-1.41	1.15				0.01
6	(j_1,j_3 & j_6) - (j_4 & j_5) - (j_2)	14.81	6.03	1.15	-7.17				0.01
7	(j_1,j_2,j_3 & j_5) - (j_4) - (j_6)	14.81	13.31	-6.65	-6.65				0.01
8	(j_1& j_4) - (j_5&j_6) - (j_2) - (j_3)	11.11	3.97	4.85	-3.47	-5.35			0.00
9	(j_1,j_2&j_3) - (j_4) - (j_5) - (j_6)	11.11	9.21	-2.95	-3.31	-2.95			0.00
10	(j_1& j_3) - (j_2) - (j_4) - (j_5) - (j_6)	8.888	3.79	-1.25	-0.73	-1.09	-0.73		0.00
11	(j_1)-(j_3) - (j_2) - (j_4) - (j_5) - (j_6)	7.407	-0.49	0.23	-1.65	0.75	0.39	0.75	0.00

The ten possible lot-streaming strategies considered. For each lot streaming strategy, the optimal group schedule obtained by using the proposed heuristics. For validation of effectiveness of heuristic solutions, all possible lot formation deployed which fulfilling those lot streaming strategy. All the lots simulated and obtained the lot completion time. Lot streaming strategy wise makespan computed (as discussed in section 2.4) for all possible group schedules (Gs). The identified the best group schedules based on the minimum makespan. The identified group schedules found same as the heuristic solution. The heuristics also suggested some near optimal schedules. This will discuss in next section. The lot streaming strategies details, number of desired lots, and maximum possible number of group schedules, the best group schedule and its makespan presented in Table 2.

6. CONCLUTION

The ten possible lot streaming strategies were identified and considered for evaluation. All possible cases were examined for validation of the heuristic. Each lot streaming strategy has one or more groups to schedule; their makespan obtained and furnished in Table 2. The proposed heuristic gives optimal solution with respect to lot sreaming strategy. From the results it is evident that the manufacturer can choose any lot sreaming strategy amoung ten. The eleventh strategy is conventional one. Due to lot streaming the time can be saved from 245 to 457 minutes. Even though all lot streaming strategies offer optimal solution, the distribution of lot completion time or distribution deviation from the m_p to be considered for uniform work load and smooth flow of jobs. Which will increases the operators motivation and morale. According to this criteria the uniform lot size is can prefer than non uniform lot size for group schedule.

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