Scheduling virtual manufacturing cells with consideration for setup times that rely on lot streaming and sequence

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Abstract

In order to reduce the total work completion time, a novel mathematical model for the issue of job scheduling in virtual manufacturing cells (VMC) is proposed in this paper. Lot-streaming is an option, and sequence dependent setup times of machines are taken into account. Virtual manufacturing cells have a collection of machinery for processing each activity, and each job has a unique processing path. There are various machine types, and there are numerous identical machines of each type spread over the shop floor. The cells in this kind of system are virtual, and machines can be distributed among the cells. The scheduling decisions in the provided mixed-integer nonlinear programming model include allocating a machine to each operation, determining the start time for each operation, determining the start time of machines, and determining the sub-lot sizes for each task. To show how the model is implemented, a few test problems have been created and resolved using Lingo.

Keywords: virtual manufacturing cells; Scheduling; lot-streaming; Mathematical model; integer programming.

1. Introduction

Today's competitive market has led the manufacturing companies to improve their production capabilities. A new generation of businesses that are dynamically linked to production needs have emerged as a result of the competitive and volatile market environment. The composition and volume of product demand fluctuate from one period to the next in a dynamic environment, necessitating flexible decision-making and planning to address this unpredictability. Cellular Manufacturing System (CMS) was consequently introduced.In CMSs, shop floor is divided into more manageable units by physically grouping the machines. Inthe cell formation Phase, it is assumed that demand is constant throughout the product lifecycle. If demand is unstable, CMS is not able to meet changes in demand. In such a case, dynamic cellular manufacturing system (DCMS) can be used based on multi-period planning horizon. In a way that at the start of each period, cells are reconfigured. When the demand change is high, replacement equipment will cost a lot. Some researchers suggested, virtual manufacturing cell (VMC) to overcome the defects of traditional CMS. In this type of system, the cells are not physical and we can have shared machines between cells. Logical grouping of jobs and machines are only in the production control system and the imagination of workers. A new approach to layout at VMC, is the scattered arrangement in which for increasing the availability, similar machines are scattered throughout the shop floor. This paper addresses the VMC problem with lot-streaming tactic.

Virtual manufacturing cell scheduling has been the subject of research. If preparation time sequence dependent machinery is not taken into account, it may be because each vehicle (machines shared between cells) performs different actions at different times. While this might result in a computation of the actual and immediate influence on finishing every job. This study focuses on the scheduling of operations in a VMC with a distributed layout and takes sequence dependent setup time into account to reduce the total amount of time and distance that the work must traverse. We also take into account lot streaming strategies that allow for job splitting.

2. Literature review

MacLean et al. for the first time in 1982 introduced the concept of virtual manufacturing cells. According to them virtual cell is not as a physical grouping of machinery, but it is as data files and processes on a controller computer (MacLean et al. 1982). Irani et al. developed a two-stage flow based approach for formation of VMCs with an objective of minimizing traveling distances (Irani et al. 1993). Kannan and Ghosh in 1996, Kannan in 1997 and 1998 explored the many part-family based scheduling rules in process layout (Kannan VR. 1997). In 2003, Ko and Egbelu presented a methodology for designing VMCs. They carried out a comparative study of dynamic and static manufacturing systems at the intent of examining the influence of variations in the product mix on the shop performance. The total preparation time and total distance transport components were considered as a measure of performance (Ko K-C and Egbelu PC. 2003). Mak et al. provided a non- linear programming for scheduling VMCs and ant colony optimization algorithm is presented (Mak et al. 2007). Kesen et al. in 2009 compared three types of cell systems, processes and virtual cells using simulation (Kesen et al. 2009). Kesen et al. gave mixed integer linear programming model with objective function for minimizing job completion time and distance jobs profiting (Kesen et al. 2010). In 2012 its previous models developed so that the job could be divided into smaller tasks (lotstreaming) (Kesen SE. and Gungor Z. 2012).

3. Problem description and model formulation

Virtual manufacturing cells

The main difference between VMC system and CMS systems is how they respond to changes in demand. In cellular manufacturing system due to the use of physical constant groups of the machine, there is a limitation to respond appropriately to changes in demand. But in virtual manufacturing cells, the cells are not physical and logical grouping of tasks, machines and workers are only in the production control system and the perceptions of workers. As a result, these cells can easily change to respond to changes in demand at the beginning of each period. In VMC systems, from any machine more than one machine is unique. Unique machines spread throughout the shop floor (Sort distributed) and each can have a different speed. In these systems a machine can belongto more than one cell at the same time.

Given the above assumptions, a VMC system can be shown in Figure 1.

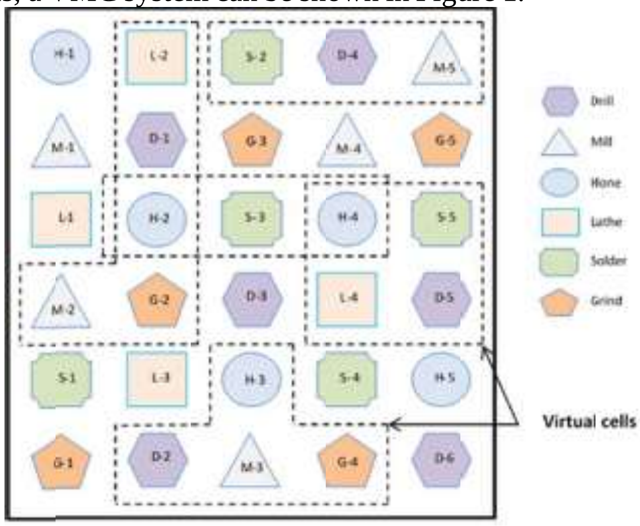

Figure 1. Schematic representation of VMCs layout

Because VMCs are proposed for small-sized and medium-sized companies that perform batch production, lot-streaming strategy has to be considered in the VMC scheduling problem. The majority of the aforementioned papers have assumed that set-up times are sequence-independentand are either negligible or included in processing times. While this assumption simplifies the analysis and/or reflects certain applications, it adversely affects the solution quality of many applications of scheduling that require an explicit treatment of set-up times (Allahverdi et al. 2010). In many manufacturing systems, the sequence of jobs processed on a machine affects set-up times.Changing production plan from a part into another one can spend a significant set-up time and effort. Therefore, sequence-dependent set-up times can be considered as an important factor in theoperations scheduling.

Problem description

In this study, a model is proposed for the scheduling of virtual manufacturing cells. The mixedinteger linear programming model will be a single objective, which is also the goal of minimizing. Model inputs include the time of each operation, the number of jobs, batch size, operations for eachjob and sequence of them. Also the number of machine types and the number of each type ofmachine, sequence dependent setup time and travelling time between machines are needed.

In the problem of virtual manufacturing cells scheduling, we have *m* machines and *n* jobs so that each job involves h_j successive operations. o_{jh} is *h*th operation of job *j* and P_{ijh} shows the unit processing time of operation o_{jh} on machine i. jobs are produced in Groups that lot size of job *j* is shown by N_j. Lot-streaming is allowed since there are alternative machines for operation o_{jh}. So, successive operations can be overlapped. Since machines are positioned in different locations in thelayout, after the operation o_{jh} is completed on machine i and before the operation $o_{j,h+1}$ is started on machine k, d_{ik} unit of travelling time occurs for job j. S_{ifj} is setup time for machine i while it is working for job *f* and now it wants to do job *j*. so s_{ij} is setup time for machine i while it is standby and now it wants to do job *j*. As a result, according to the amount of operations S_{ifj} or S_{ij}, setup timebetween two sequence for machine i must be considered.

Problem of VMC scheduling includes:

- Assigning proper machine to each operation
- Obtain the sub lot size for each job
- Calculated the starting time of each operation
- Determine the time to start the job in any order

All of the above should be selected so that all jobs will be done in the shortest time possible.The following assumptions should be considered:

- Operations must be performed one after another according to the problem input
- Each machine can only perform one operation at a single time.
- Sequence of operations, setup time depends on the sequence, process time, batch size and the travelling time between the machines are pre-determined.
- The machines are fixed and do not change their location.
- Number of sub-lot for all jobs is fixed and known in advance.
- All job must be available at time zero and is not acceptable in any new work.
- Each job can visit any machine at most once.
- There is no preference for doing Jobs.
- Machine Breakdown and maintenance activities are not considered.

Parameters:

i,k: indices for machine (i, k=1, . . . ,m) where m is the number of machines in the systemj,f:
indices for job (j=1, . . . , n) where n is the number of jobs in the system
h,r: indices for operation (h=1, . . . , hj) where h_j is the number of operations to be performed forjob j
p,q: indices for sub-lot (p=1, . . . ,L) where L is the number of sub-lots
l: indices for order on each machine (l=1, . . . , li) where li is the number of operations assignedto machine i
N_j: lot size for job j
P_{ijh}: unit processing time of operation o_{jh} on machine id_{ik}:
travelling time between machine i and k
S_{ij}: machine i setup time for doing job j while machine i was standby
S_{ifj}: machine i setup time for doing job j while machine i was do job f in previous order.SQ_{jhi}: 1 if machine i capable of doing *j*th operation of job j to be, 0 otherwise.
M: sufficiently big numberDecision
variables
C_{max}: makespan or maximum completion time of jobs to leave the systemV_{jp}:
number of parts to be produced for job j in lot p
Y_{ijhp}: 1 if machine i is selected for the *p*th lot of operation o_{jh}, 0 otherwise

X_{ijhlp}: 1 if operation o_{jh} for lot p is performed on machine i in order l, 0 otherwise
Z_{ikjhp}: 1 if operation o_{jh} is performed on machine i and operation $o_{j,h+1}$ is performed on machinek, 0 otherwise.
t_{jhp}: starting time of operation o_{jh} for the *p*th lot Tm_{il}:
starting time of work on machine i in order l

Minimize C_{max}Subject to

$$C_{\max} \geq t_{jhp} + V_{jp}P_{ijh} - M(1-Y_{ijhp}) \quad \forall i,j,h,p \quad (1$$

$$\sum_p V_{jp} = N_j \quad \forall j \quad (2$$

$$t_{jhp} + V_{jp}P_{ijh} - M(1-Y_{ijhp}) + \sum_k d_{ik}Z_{ikjhp} \leq t_{j,h+1,p} \quad \forall i,j,p,h : i \neq k, h \neq h_j \quad (3$$

$$Tm_{il} + S_{ij}X_{ijhlp} + V_{jp}P_{ijh} \leq Tm_{i,l+1} + M(1-X_{ijhlp}) \quad \forall i,j,h,l,p : l = 1 \quad (4$$

$$Tm_{il} + \sum_f \sum_r \sum_q S_{ifj}(X_{ifr,l-1,q})(X_{ijhlp}) + V_{jp}P_{ijh} \leq Tm_{i,l+1} + M(1-X_{ijhlp})$$
$$\forall i,j,h,l,p : l \neq l_i, l \geq 2 \quad (5$$

$$Tm_{il} + S_{ij}X_{ijhlp} \leq t_{jhp} + M(1-X_{ijhlp}) \quad \forall i,j,h,l,p : l = 1 \quad (6$$

$$Tm_{il} + \sum_f \sum_r \sum_q S_{ifj}(X_{ifr,l-1,q})(X_{ijhlp}) \leq t_{jhp} + M(1-X_{ijhlp}) \quad \forall i,j,h,l,p : l \geq 2 \quad (7$$

$$Tm_{il} + S_{ij}X_{ijhlp} \geq t_{jhp} - M(1-X_{ijhlp}) \quad \forall i,j,h,l,p : l = 1 \quad (8$$

$$Tm_{il} + \sum_f \sum_r \sum_q S_{ifj}(X_{ifr,l-1,q})(X_{ijhlp}) \geq t_{jhp} - M(1-X_{ijhlp}) \quad \forall i,j,h,l,p : l \geq 2 \quad (9$$

$$\sum_j \sum_h \sum_p X_{ijhlp} \leq 1 \quad \forall i,l \quad (10$$

$$\sum_p \sum \sum X_{ijh,l+1,p} \leq \sum_j \sum_h \sum_p X_{ijhlpj} \quad h \quad \forall i,l : l \neq l_i \quad (11$$

$$\sum_i Y_{ijhp} \geq 1 \quad \forall j,h,p \quad (12$$

$$Y_{ijhp} \leq SQ_{jhi} \quad \forall i,j,h,p \quad (13$$

$$\sum_l X_{ijhlp} = Y_{ijhp} \quad \forall i,j,h,p \quad (14$$

$$2Z_{ikjhp} \leq Y_{ijhp} + Y_{kj,h+1,p} \quad \forall i,k,j,h,p : h \neq h_j, i \neq k \quad (15$$

$$Z_{ikjhp} \geq Y_{ijhp} + Y_{kj,h+1,p} - 1 \quad \forall i,k,j,h,p : h \neq h_j, i \neq k \quad (16$$

$$V_{jp} \geq \sum_i Y_{ijhp} \quad \forall j,h,p \quad (17$$

$$Z_{ikjhp} = 0 \quad \forall i,k,j,h,p : i = k \quad (18$$

$$Z_{ikjhp} = 0 \quad \forall i,k,j,h,p : h = h_i \quad (19$$

$$C_{\max} \geq 0 \quad (20$$

$$V_{jp} \geq 0 \text{ and integer} \quad \forall j,p \quad (21$$

$$t_{jhp} \geq 0 \quad \forall j,h,p \quad (22$$

$$Tm_{il} \geq 0 \quad \forall i,l \quad (23$$

$$Y_{ijhp} \in \{0,1\}\ X_{ijhlp} \quad \forall i,j,h,p \quad (24$$

$$\in \{0,1\} X_{ifrlq} \quad \forall i,j,h,l,p \quad (25$$

$$\in \{0,1\}\ Z_{ikjhp} \quad \forall i,f,r,l,q \quad (26$$

$$\in \{0,1\} \quad \forall i,k,j,h,p \quad (27$$

Objective function is to minimize the make span value that is used in order to minimize the total completion time of jobs. Constraint (1) ensures that the make span is greater or equal to the completion of all jobs. Constraint number (2) shows that summation of sub-lot size is equal tolot size for each job. Constraint set (3) guarantees that the succeeding operation of any job for any sub-lot can be started only after the preceding operation is completed and transported between respective machines. Constraint set (4 & 5) enforces that between the consecutive operations to be executed on any machine; the succeeding one can only be started after the preceding one is completed and setup time is spend. Constraint sets (6 & 7 & 8 & 9) guaranteethat if X_{ijhlp} is equal to 1 , the starting time of o_{jh} for sub-lot p and the starting time of the workon machine i in order l plus setup time are the same. Constraints number (10) ensures that at most one operation will be done on every machine in order l. Also limits the number (11) showsthat for machine i until l has not accepted its operation, it will not be able to get it another operation for order l + 1. Constraint (12) ensures that the o_{jh} for the sub-lot *p* must be assignedto only one machine (Also, it should be allocated to one of the machines). On the constraint number (13) we can say that if machine i has the ability to perform o_{jh}, it can select it. Constraint set (14) makes sure that if operation o_{jh} for sub-lot p is performed on machine i, this operation must be performed on machine i in any order. Constraint sets (15) and (16) ensure that if operation o_{jh} and operation oj,hþ1 for sub-lot p are performed on machine i and k respectively, Z_{ikjhp} can only be equal to 1, 0 otherwise. Constraint set (17) ensures that if operation o_{jh} for sub-lot p is performed on machine i, the number of items to be processed in jobj for sub-lot p (ie, sub-lot size) must be greater than zero. The constraints (18) and (19) show that if the machine does not change or is ongoing on the last operation, Z_{ikjhp} value is zero. Constraint numbers (20), (21), (22), (23), (24), (25), (26) and (27) indicate that the variables arenon-negative.

Kesen and Gunger in 2012 VMC developed a model for the VMC system scheduling so that thework could be divided into smaller tasks (lot streaming). This model has the following problems:

- ✓ The main problems are the lack of a parameter that indicates the machine is able to perform which operations. To solve this problem we define the parameter SQ_{jhi} and we resolve this problem by taking the Constraints 13.
- ✓ Also there is not suitable Constraints that covers all states of Z_{ikjhp} and For this purpose, Constraints of 18 and 19 were considered.
- ✓ In this model $X_{ijh.l+1,p}$ can be 1 while X_{ijhlp} was 0, that This had a negative impact on Tm_{il}. For example, Tm_{il} value in the first and second order was zero, but in third order, it starts to get value. To solve this problem, Constraint 11 was considered.

4. Numerical examples

To better understand the model, two illustrative examples will be described in the following that thefirst example is simpler than the second one. These examples are solved by Lingo software Version 14. Also a computer with Intel core i5-4200M 2.50 GHz up to 3.10 GHz processor and 6 GB Rammemory is used.

Example 1: In this example, there are three types of machine A, B and C that for each type, thereare two unique machines. Machines number is available in Table 1. The number of sub-lot is 2 and 4 is the maximum number of order in machine.

In this system, there are two jobs that you can see in Table 2. The sequence and process time for each operation and batch size are given in this table. For example, each lot of job 1 meets Type B machine and then Type C machine. However, for type B machine, machine 3 at 25 units and machine 4 at 23 units of time do the operation. Also batch size to produce job 1 is 20 time units.

Table 3 represents the setup time of standby mode for different machines (s_{ij}). Table 4 shows sequence dependent setup time for each type of machine. According to the sequence of jobs operation if machine i could not get a job transfer to another job, the sequence dependent setup timecan be considered zero. For example, in the case of machine type C, if the machine has finished job2 and wants to start job 1, setup time will be 8 time units. Table 5 shows the SQ_{jhi} values for each job separately. For example, only machines 3 and 4 can perform a second operation of job 2, they have received amounts 1. Table 6 shows the travelling time between machines.

Table 1: Machine types and individual machines belonging to each machine type

machine type	machine umber
A	1 , 2
B	3 , 4
C	5 , 6

Table 2: Lot sizes, operation sequences and process time of the jobs

job j	sequence operation and process time	lot size
1	B(25,23) → C(18,17)	20
2	A(32,35) → B(12,11) → C(15,14)	17

Table 3: Machine setup time from standby mode (S_{ij})

i \ j	1	2
1 , 2	0	10
3 , 4	5	7
5 , 6	7	3

Table 4: Sequence dependent setup time (S_{ifj})

	A: i=1,2		B: i=3,4		C: i=5,6	
From f \ To j	**1**	**2**	**1**	**2**	**1**	2
1	0	0	0	10	0	10
2	0	0	20	0	8	0

Table 5: the ability of machine i to produce *h*th operation for each job

	h \ i	1	2	3	4	5	6
j=1	1	0	0	1	1	0	0
	2	0	0	0	0	1	1
	3	0	0	0	0	0	0
J=2	1	1	1	0	0	0	0
	2	0	0	1	1	0	0
	3	0	0	0	0	1	1

Table 6: Travelling time between machines

achine	1	2	3	4	5	6
1	0	3	2	1	2	3
2	3	0	1	4	1	2
3	2	1	0	2	3	1
4	1	4	2	0	1	3
5	2	1	3	1	0	4
6	3	2	1	3	4	0

After coding the above example in lingo and solving it, model outputs that are answers to the example, are shown by figure 3. Also sub-lot 1 and 2 of job 1 include 10 lot for them and sub-lot 1 and 2 of job 2 include 8 and 9 items respectively. As the shortest possible time to complete all the Jobs is 561 time units that is global optimum for this example. The example above was dissolved in 4 minutes and 37 seconds (See Figure 2 in the status window output Lingo). Itshould be noted that the value of M, is intended one hundred million.

Figure 2: Lingo status window output in Ex mple 1

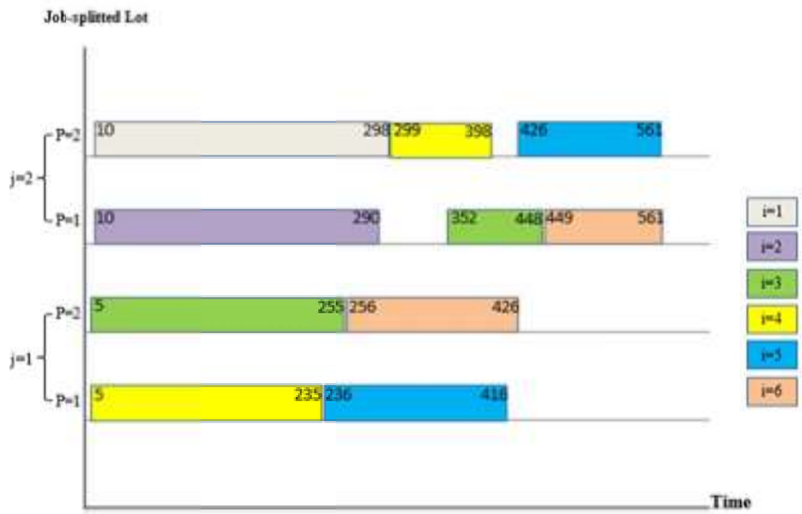

Figure 3: Gantt chart for Test Problem No. 1

As can be seen, all the hypotheses are considered, For example, no machine is working two different jobs at a time and the sequence of operations are involved in doing jobs strictly and sequence dependent setup time is considered.

According to Figure 2, operation o_{21} process starts at 10 by machine 2 and completes in 290. The next operation will start at 352 and end at 448 and finally, the first sub-lot of job 2 after thelast operation in the machine 6, the 561 times is ready for delivery.

Lags that occur between the various operations of a job, are Due to the following:

- Time of travelling between machines
- sequence dependent setup time for change job allocated to each machine
- Lack of appropriate machine for the allocation of the next operation

If the setup time was not considered, Completion time of Jobs is reduced to 546. So in order togain a more realistic calculation, sequence dependent setup time should also be considered. If we do not consider lot streaming and solve above example (p=1), we witness the completion time of the Jobs (make span) increased to 983 times. Thus lot streaming is leading to a reduction of make span, But this does not mean that the number of sub-lot will be further reduced completion time of Jobs, But according to the setup times and travelling time and number of machines, the amount of make span will increase or decrease. In the above example, for P = 3 make span value increased to 578.

Example 2: This example is developed in the previous example, there were 2 jobs in the previous example, but in this example, we are planning to have 3 jobs. Machines Number is available inTable 1. Also, P = 2 and L = 3 is considered. Table 7, shows jobs and sequence operations of them and process time by the appropriate machine. Table 8 and Table 9 show (S_{ij}) and (S_{ifj}) values respectively. SQ_{jhi} values for jobs 1 and 2 is given in Table 6 and for job 3 in Table 10. Timeinterval between machines is given in Table 5.

Table 7: Lot sizes, operation sequences and process time of the jobs

job j	sequence operation and process time	lot size
1	B(25,23) → C(18,17)	20
2	A(32,35) → B(12,11) → C(15,14)	17
3	C(21,24) → A(25,22)	27

Table 8: Machine setup time from standby mode (S_{ij})

i \ j	1	2	3
1 , 2	0	10	8
3 , 4	5	7	0
5 , 6	7	3	4

Table 9: Sequence dependent setup time (S_{ifj})

machine type	A : i = 1,2			B: i=3,4			C: i=5,6		
from f \ to j	1	2	3	1	2	3	1	2	3
1	0	0	0	0	10	0	0	10	14
2	0	0	12	20	0	0	8	0	7
3	0	11	0	0	0	0	16	12	0

Table 10: The ability of machine i to produce *h*th operation for each job (SQ_{jhi})

j = 3

h \ i	1	2	3	4	5	6
1	0	0	0	0	1	1
2	1	1	0	0	0	0
3	0	0	0	0	0	0

After the example code in Lingo, optimum solution (global optimum) within 19 minutes and 25seconds was obtained (Refer to Figure 4). The minimum time for completion of Jobs, 644 time units was achieved. Also $V_{11} = 10$, $V_{12} = 10$, $V_{21} = 9$, $V_{22} = 8$, $V_{31} = 14$, $V_{32} = 13$ was calculated.

Figure 4: Lingo status window output in Ex mple 2

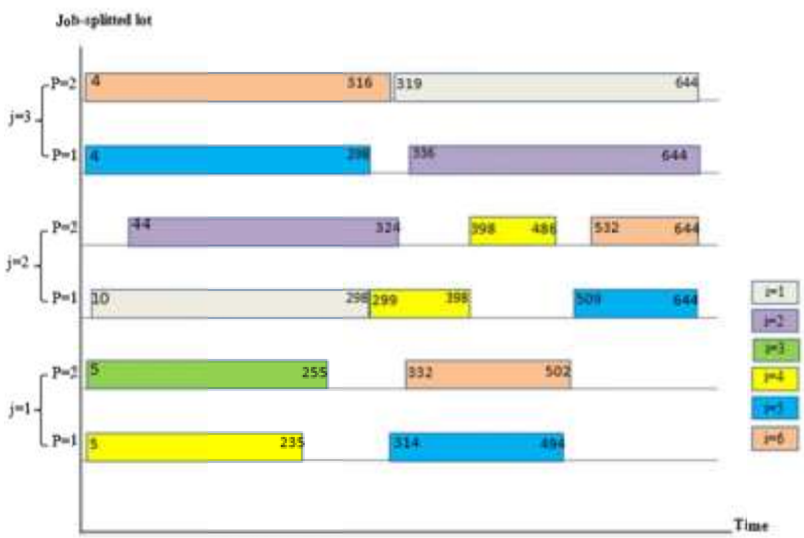

Figure 5: Gantt chart for Test Problem No. 2

5. Discussion and conclusions

A future design is described for a virtual manufacturing cell. Both CMS and FMS (flexible manufacturing system) advantages are built into this system. The challenge of VMC system scheduling with consideration for sequence dependent setup time and an unstudied lot streaming approach is the major problem covered in this study. We have thought about the scenario when there are multiple jobs and each job is made up of subsequent operations. There are many distinct types of machines that can complete tasks, and each one is made up of numerous machines with various processing speeds. The workshop is filled with many machines. Transit time between machines is also taken into account. To determine the minimum completion time of jobs, we have provided a mixed integer nonlinear programming model. The allocation of machines, the beginning time for each operation, and the sub-lot size for each work are the three most crucial model outputs. The create span's dimensions are extremely dependent on the the number of sub-lots. This research's extension is in some

aspects. The use of exact solution methods greatly increases the time required to tackle problems of a big magnitude. Thus, using meta-heuristic techniques to this problem may be helpful. also observe the device A system's breakdown and upkeep can result in the creation of fresh research and model development.

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