INTEGRATED PRODUCTION SCHEDULING AND RESCHEDULING IN AN FMS UNDER TOOL AVAILABILITY CONSTRAINTS

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Abstract Scheduling and Rescheduling of production in flexible manufacturing system (FMSs) have been extensively researched over the years and it continues to attract the interest of both academicians and practitioners. The present work focuses on the problems of generating a priority based scheduling rule using Genetic Algorithms (GAs) and validating the same by comparing with the different scheduling rules based on standard processing time. The comparison of various scheduling rules with regard to manufacturing performance measures like manufacturing lead-time, Plant capacity, Utilization, Work in process and WIP ratio has been made. Uncertainties in the production environment results in deviations from the generated schedules. The uncertainties like increased order priority and arrival of new orders have been considered while rescheduling. The focus is also made to take into consideration the tool availability criterion, where in the optimum number of different tool types to produce the parts has been computed using a proposed heuristic for both initial schedule and after reschedule.

INTRODUCTION

Global competition is forcing the present day manufacturing industry to design and implement production system, which are more flexible with respect to the product variety and at the same time more productive. The effectiveness of a scheduling rule used to prioritize depends on a number of factors such as performance criteria, due date tightness, etc. Authors in their earlier work [10] have considered the problem of scheduling in an FMS based on due dates. Genetic Algorithm (GAs) which has been applied to a variety of function optimization problems has been successfully used in the present work to generate a scheduling rule. Thus generated scheduling rule has been validated by comparing with the scheduling rules based on standard processing time.

The generation of new and modified production schedules is becoming a necessity in modern manufacturing environment. The four different types of uncertainties that normally cause discrepancies between the actual output and the planned output are increased order priority, rush order arrival, order cancellation and unforeseen machine breakdown. In the present work the first two uncertainties have been considered while rescheduling.

One of the issues related to loading and operating problems in an FMS is the rapid and timely provision of cutting tools to the appropriate machines. In many batch-manufacturing applications, the cost of cutting tools is a significant proportion of the total production cost. In the present work the heuristic proposed by the authors [4] has been used to compute one optimum number of tool types required for production.

METHODOLOGY

Scheduling. The problem of generating a priority based scheduling is formulated as a genetic algorithm problem and solved as follows:

a) The chromosomes are identified as a sequence of parts being produced.
b) The genes (symbols) are identified as part types.
c) The initial population has been generated randomly.
d) The total completion time of all the part types for a particular sequence of parts has been considered as the objective function.
e) The selection of chromosomes for reproduction has been done by evaluating the fitness value obtained from the objective function.
f) The selection of chromosomes for crossover has been done by using Partially Mapped Crossover operator followed by mapping and legalizing the offsprings.
g) The selection of chromosome for mutation has been done by using Displacement Mutation operator.
h) The chromosome with optimum value of objective function after all iterations have been considered as the solution to the problem of finding the best scheduling rule.

The value of the objective function (Z) while generating a scheduling rule using GA has been computed as follows:

$$Z = Min S\, Tp_i t_j + Wp_i \quad \text{---------} \quad 1$$

where i=1 to n part types , j=1 to m tool types
Tpt = processing time of part **p** with tool **t.**
Wp= total waiting time of part for operation on all machining centers.

Rescheduling. The scheme of rescheduling in the events of increased priority and arrival of new order is summarized as follows:

Increased priority**:** Whenever the priority of any order (job type) is increased, all the succeeding tasks of this order are advanced in time The next task of this order will start as soon as the preceding task is completed. The tasks of this high priority order are marked 'urgent" so that the ready time of the remaining tasks (of this order) becomes fixed in time. The assignment of urgent task does not follow the dispatching rule, while normal task do. Therefore, when there is a choice between an urgent task and a dispatching rule task (say SPT) the urgent task will be selected for assignment. The procedure to the solve the problem of increase in priority is as follows:

Run the schedule obtained from GA starting at time T=0,1,2…until the schedule is complete. At any time t, if there is an increase in priority then, find the job whose priority is increased. Assign the highest priority to this order and revise the task status. Assign the same priority to all the task belonging to this order.

If the increased priority task is currently not loaded on any machine and if machine required by the increased priority task is free, then assign task to the machine.

Otherwise pre-empt the machine and start high priority task immediately and update the system status. Then advance all the remaining tasks to start immediately.

New order arrival: When a new order arrives, it is first determined whether it is a rush order or a normal order. If it is a normal order, it is merged into the current schedule. If it is a rush order, then the highest priority is assigned to it and it is treated similarly to that of an increased priority order.

Heuristic for computing optimum number of tool types

Notations: C_p= Completion time of part **p**,
$\mathbf{T_{pt}}$= Processing time of part **p** with tool **t.**
$\mathbf{T_{p'tm'}}$ =Processing time of part **p'** with tool **t** on center **m'**
$\mathbf{L_{mm'}}$ = Tool transfer time between machining centers **m** and **m'**, $\mathbf{E_{tmm'} = E_{tm} - E_{tm'}}$ where,
$\mathbf{E_{tmm'}}$=Elapsed time since the start of the current operation upto the present time on machining center **m** for tool **t**
$\mathbf{E_{tm}}$ =Time at which machining center can start its operation if tool **t** is allocated to center **m.**
$E_{tm'}$ =Time at which machining center **m'** can start its operation with tool **t** if tool is allocated to **m'.**
W_p = Total waiting of part for tool + Total waiting time of part for operation on all the machining centers.
$W_{mm'pp'}$ = The waiting time of part **p** on center m when the tool **t** is allocated to part **p'** on **m'.**

$$C_p = S\, T_{pt} + W_p \quad \text{---------------------} \quad 2$$

The waiting time of part **p** (W_p) is the sum of waiting time of part for tool and the waiting time part for the machine to be free. W_p is minimum when these two waiting time are minimum. The completion time is dependent on waiting time of the parts when it waits for the tool ($\mathbf{W_{mm'pp'}}$). The tool allocation has been done in such a way as to minimize this waiting time. If there is demand for tool **t** from machining center **m** and **m'**, the waiting time of part **p** on **m** when tool is allocated to part **p'** and **m'** is given by

$$\mathbf{W_{mm'pp'} = T_{p'tm'} - E_{tmm'} + L_{mm'}}$$

$$\mathbf{W_{mm'pp'} = (E_{tm'} + T_{p'tm'} + L_{mm'}) - E_{tm}} \quad \text{\_\_\_\_\_\_} \quad 3$$

The equation 3 has been used to compute the waiting time of a machine **m** when it has to wait for a particular tool **t,** if the tool **t** happened to be assigned to another machine. A decision regarding the duplication of a particular tool type or transfer of a particular tool type from one machine to another has been taken keeping in mind the waiting time of a part. The duplication of a particular tool type is recommended when there is situation where part is made to wait for a tool type to transfer from one machine to another. The transfer of a particular tool type is recommended, if there is a situation where part does not wait for a tool type when that particular tool is transferred from one machine to the required machine. Thus, the tool transfer details can be computed for a particular combination of part types, tool types and machines.

ILLUSTRATION

A loop layout with six machines (M1 toM6) and their positions as shown in figure 1 has been considered for illustration. The machines have the known distances between them in the layout. The part type considered in the illustration (P1, P2, P3 and P4), the sequence of operation of each part type along with delivery time is shown in the table 1. The part transfer time, tool transfer time and load/unload times in minutes between any two machines is shown in the table 2. The value of time within the parentheses of table 2 indicate tool transfer time. The value of time of outside the parentheses indicate the part transfer time. The processing time of part types and setup times on various machines along with tool types required for specific times is shown in the Table 3.

The following two uncertainties have been considered independently for rescheduling :

1. Increase in priority of part P3 at time 40 minutes.

2. Arrival of new order for part type 5 at time 60 minutes

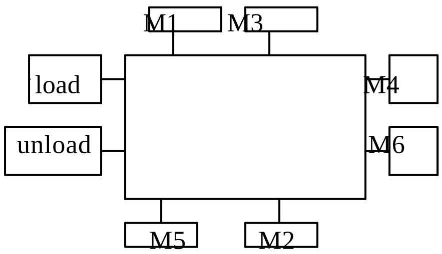

Fig. 1 Loop layout with 6 machines.

Table 1: Part types, their sequences of processing and delivery times

Part type	Sequence	Delivery Time
P1	1 3/6 4 5	12 hours
P2	3 2 5 6	11 hours
P3	2 5 4/5 3	13 hours
P4	1 4 3 5	11 hours

Table 2: Part transfer, tool transfer and load /unload times for different machines.

	M1	M3	M4	M5	M2	M6
M1	0	1(1)	2(2)	2.5(3)	3.5(1)	3(2)
M3	1(1)	0	1.5(1)	2(2)	3(3)	1(1)
M4	2(2)	1.5(1)	0	1(1)	2(2)	2.5(3)
M5	2.5(3)	2(2)	1(1)	0	1.5(1)	2(2)
M2	3.5(1)	3(3)	2(2)	1.5(1)	0	1(1)
M6	3(2)	1(1)	2.5(3)	2(2)	1(1)	0
Load	1.5	2.0	3.0	3.5	2.5	2.0
Unload	2.0	2.5	3.5	3.0	2.0	1.5

Table 3: Processing time, setup time and tool type to produce the parts.

P1	**M1(2)**	**M3(1)**	**M4(0)**	**M5(2)**
	T!(3)T4(6)T8(6)	T9(5)T10(5)T2(3)	T3(6)T4(9)T5(2)	T6(4) T7(9) T8(2)
	M3(1)	**M2(2)**	**M5(2)**	**M6(3)**
P2	T5(6) T8(3)	T9(2) T7(6)	T4(6) T5(3)	T8(6) T5(2)
	M2(2)	**M5(1)**	**M4(2)**	**M3(1)**
P3	T5(3)T6(6) 7(5)	T1(2) T3(5) T2(3)	T5(4) T4(6)	T1(8) T7(6)
	M1(1)	**M4(3)**	**M3(0)**	**M5(3)**
P4	T6(5) T4(9) T7(8)	T9(6) T5(4)	T6(9) T2(9)	T10(11) T4(7)

Table 4: Rush order arrived at time 60 minutes with processing time, setup time and tool type required.

	M1 (3)	M2 (2)	M3 (3)	M4 (4)
P5	T1(5) T2(6)	T3(5) T4(6)	T7(5) T8(5)	T3(6) T4(6)

As per the above information, the scheduling rules obtained based on standard processing time are; Longest processing time (LPT) =P4 P1 P3 P2, Job ranked by most work remaining (MWKR)=P4 P1 P3 P2, Job ranked by least schedulable work remaining (LWKS) = P1 P3 P4 P2, Shortest processing time (SPT) = P2 P3 P1 P4, Job ranked by least work remaining (LWKR) = P2 P3 P1 P4, Job ranked by most schedulable work remaining (MWKS) = P2 P4 P3 P1. The problem has been solved using Genetic Algorithm and the optimum-scheduling rule generated by GA has been found as P1 P4 P3 P2. The scheduling rule generated by GA has been validated by comparing with the various scheduling rules and the results have been presented in Table 5.

The optimum sequence obtained from GA has been used for rescheduling. The initial schedule and rescheduled time horizon is plotted for the above cases using a Gantt chart and has been shown in the figure 2 to 4. The Fig. 2 refers to the Gantt chart pertaining to the schedule before rescheduling. The Fig. 3 is the Gantt chart when the priority of job 3 was increased at time T=30 min. This indicates the advancement of the task (job P3) on M4 and M3. The job 3 has been completed earlier (68.5min) than the original schedule (102 min). The total completion time has found to increase to 129min from 110.5min. The Fig.4 is the Gantt chart when the arrival of new order (job P5) is considered as a normal order. The job P5 has been merged to the current schedule and the total completion time is found to increase to 130.5min.

The optimum number of tool types required after rescheduling has been computed using the proposed heuristic. It has been found that there is no change in the number of tool types required for both the uncertainities. The number of tool types required for the schedule generated by GA and after rescheduling has been presented in the table.6

Table 5: Comparison of scheduling rule generated by GA with other scheduling rules.

Scheduling rule no	Scheduling rules	Total completion time (min)	Mfg. Lead time (hr)	Production Rate (Units/ hr)	Plant capacity (Units/ week)	Utilization (%)	WIP (Units)	WIP ratio
1	GA	110.5	1.84	0.543	273.67	73.08	4.38	0.73
2	LPT	112.5	1.875	0.533	268.63	74.45	4.46	0.743
3	MWKR	112.5	1.875	0.533	268.63	74.45	4.46	0.743
4	LWKS	124.5	2.075	0.482	242.93	82.23	4.93	0.822
5	SPT	126.5	2.11	0.474	238.9	83.72	5.02	0.837
6	LWKR	126.5	2.11	0.474	238.9	83.72	5.02	0.837
7	MWKS	136.5	2.275	0.439	221.26	90.39	5.42	0.903

Table 6: Optimum Number of tools required and transformation details.

Tool types	Optimum No. of tools required (without tool sharing)	Optimum No. of tools required (with tool sharing)	Tool transformation details for initial schedule
T1	3	1	6.5M1 – 21M5, 23M5 – 85.5M3
T2	2	2	No transformation
T3	2	1	28M5 – 35M4
T4	3	2	33.5M1 – 41M4
T5	5	2	7.5M2 – 39M5, 9M3 – 50M4, 42M5 – 53M6
T6	4	1	13.5M2 - 19.5M1, 24.5M1 – 55M5, 59M5 – 66.5M3
T7	4	1	28.5M2 – 33.5M1, 41.5M1 – 59M5, 68M5 – 93.5M3
T8	4	2	12M3 – 47M6, 18.5M1 – 68M5
T9	3	2	22.5M2 – 55M4
T10	2	1	30.5M3 – 89.5M5

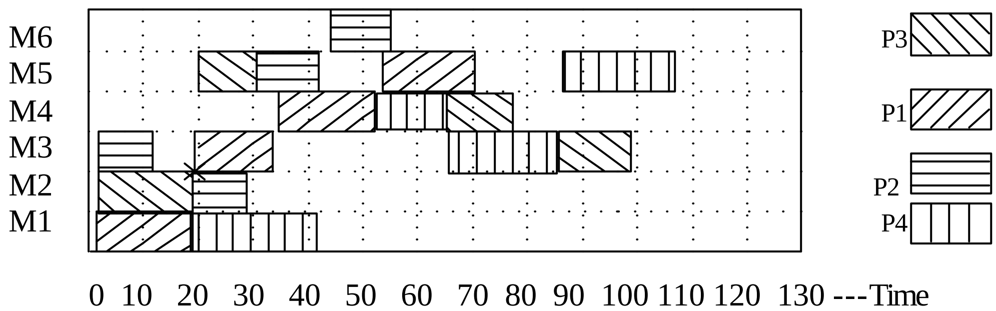

Fig.2 Initial example for chosen example

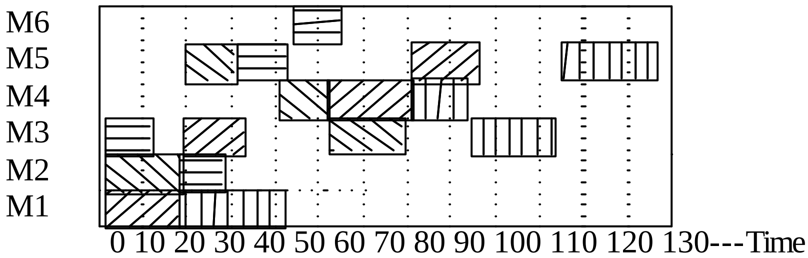

Fig. 3 Job 3 priority increased at T=40.

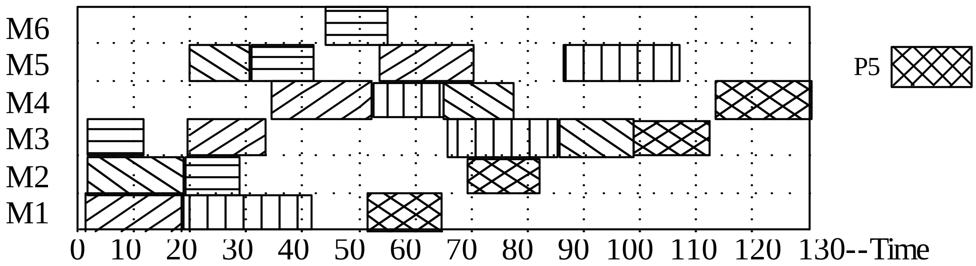

Fig.4 New order arrived at T=60 with priority 5

CONCLUSION

Scheduling rules are used to prioritize jobs on various resources. The effectiveness of a rule depends on number of factors such has performance criteria, due date tightness etc., Genetic Algorithms (GAs) which have been applied to a variety of function optimization problems has been successfully used in the present work to generate a scheduling rule. The scheduling rule generated by GA has been validated by comparing with the existing scheduling rules based on standard processing time. Two types of uncertainties like increase in priority and arrival of new order have been considered while rescheduling. A heuristic proposed by the authors in their earlier work has been used to compute the optimum number of tool types required with out effecting the manufacturing performance measures. Thus, it is possible to avoid duplication of expensive tools.

REFERENCES

Kim. Y.D and Yano C.A A due date based approach to part type selection in FMS *INT.J.PROD.RES, 1994,vol.32,No.5, 1027-1043*
.

Roh.H.K and Kim.Y.D. Due date based loading and scheduling methods for FMS with a Automatic tool transporter. *INT.J.PROD.RES.1997,vol.35,No.11, 2989-3003*.

Mukhopadhyay S.K and Sahu S.K. Priority based tool allocation in a FMS I*NT.J.PROD.RES.1996.vol.34,No.7, 1995-2017*4.

Rajaprakash B.M and Basalalli V.K, et.al. Scheduling of work pieces and cutting tools using heuristics and Dijkastra Algorithm within a flexible manufacturing cell. *IT-bHU,VARANASI, S-IV A5-1 to A5-9*, *January 2000*.

Sabuncuoglu. A study of scheduling rules of flexible manufacturing systems: a simulation approach *INT.J.PROD.RES.,1998. VOL36,NO.2, 527-546*.

Liu and Mac Carhy.B.L. The classification of FMS scheduling problems. *INT..J.PROD.RES.,1996. VOL.34,NO.3, 657-664*.

Mukhopadhya .S.K and Sahu .S.K. Priority based tool allocation in a flexible manufacturing system. *INT..J.PROD.RES.,1996. VOL.34,NO.7, 1995-2017*.
.

Balagun.O.O.and Proplewell.K. Towards the integration of flexible manufacturing systems scheduling *INT..J.PROD.RES.,1999. VOL.37,NO.15, 3390-3428*.

Nayak.G.K. and Acharya.D. Part type selection, machine loading and part type volume determination problems in FMS planning *INT..J.PROD.RES.,1998. VOL.36,NO.7, 1801-1824*.

Rajaprakesh.B.M Basalalli. V.K, et.al. Some studies on applicability of production scheduling in an FMS using genetic algorithm under tool availabality constraints. *International Conference on recent advances in materials and material processing. Feb 2002,IIT Kharagpur*.