IMPROVEMENT OF PERFORMANCE IN A MAINTENANCE JOB SHOP

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Abstract: Scheduling is an important aspect of the shop floor management system, which has a significant impact on the performance of the system. In a dynamic job shop, jobs arrive at the shop with an inter-arrival times described by a specified probability distribution.

Scheduling a job shop essentially involves deciding the order or priority for the jobs waiting to be processed at each machine so as to satisfy the technological constraints and to meet the desired objective. The decision as to which job is to be loaded on a machine is normally made with the help of the scheduling rules.

A detailed investigation of the existing Job Shop (Central Machine Shop) was carried out by Work Sampling Study which revealed that the percentage utilization of the machines is very low. Based on the reasons for low utilization of the machines, a Job Shop Scheduling was taken up to enhance the performance of the job shop.

This work deals with an analysis of the performance of various scheduling rules in a Job Shop Production System (JSPS). Different conditions arising out of due date settings and inter arrival times of jobs are considered. Different sets of scheduling rules such as processing time based rules, due date based rules, and some combination rules have been considered for study. The performance measures evaluated are *mean flow time, mean tardiness and percentage of tardy jobs.* A comparative analysis of the relative performance of these rules is also carried out.

Key words: Scheduling rules, mean flow time, mean tardiness, percentage of tardy jobs, work sampling, simulation.

1. Introduction

Scheduling in a job shop is an important aspect of a shop floor management system, which has a significant impact on the performance of the shop floor. Each job consists of a specific set of operations, which have to be processed according to a given technical precedence order (routing). The aim of the planning process is to find a schedule for processing all jobs, optimizing one or more goals (minimizing mean flow time or minimizing mean tardiness etc.).

Blackstone et al. [2] defined Scheduling rules as: ‘rules used to select the next job to process from jobs waiting for service’. Combination rules which make use of both process-time and due-date information are also proposed. e.g. Least Slack rule, Critical Ratio, etc. Scheduling rules can be very simple or extremely complex. Pierreval, H., and Mebarki, N., [4], Blackstone et al. [2], Baker [1], Ramasesh [5] have dealt with many scheduling rules. The scheduling rule’s performance depends on the configuration of the studied system, the operating conditions and the performance criterion used to evaluate the scheduling rules. Haupt, R [3] classified Scheduling or Dispatching rules as:1.Process-time based rules 2.Due-date based rules 3. Combination rules and 4. Rules that are neither process-time based nor due-date based. He also proposed the rules which do not fall into any of the above categories and loads the jobs depending on shop floor conditions rather than on the characteristics of the jobs. An example of this type of rule is the WINQ rule (total work-content of jobs in the queue for the next operation on a job).

The present work is carried out in Central Machine Shop, established to cater the repair/ reconditioning of plant and equipment and manufacture of spares required for a Steel Plant. The machining section has over 100 major machine tools including lathes, milling, boring, planning, slotting, shaping, grinding and other machines.

1.1 Motivation to Present Work

In the preliminary investigation, it was observed that most of the machines are idle. The reasons for most of the machines to be idle have been investigated by Work Sampling Technique. Work sampling is a method of finding the percentage occurrence of a certain activity by statistical sampling and random observations.

The results of both pilot and random study are given in table-1. The reasons for idle time of the machines were also listed during the study. The existing performance of the job shop was observed to be less than 45% for most of the machines

Most important reasons identified by work sampling are as follows.

- Assignment of work distribution to workers is not proper.
- Allotment of jobs on the machines is not proper.
- On most of the machines, jobs are delayed.

It was found that the allotment of jobs on the machines is not systematic. The jobs are being loaded randomly as and when they arrive without taking into consideration the due dates, processing sequence, processing time etc. Due to this most of the jobs are delayed at the same time most of the machines are also idle.

1.2 Scope of Present Work

The present work is focused on the allotment of jobs to machines, to improve the performance of the job shop by making use of inter-arrival times, due date settings and processing times.

A comparative analysis of the relative performance of different scheduling or dispatching rules was also made.

2. Approach Adopted in the Present Study

The present work involves the following steps:

2.1 Understand the Various Aspects of the Job Shop Scheduling Problem

In a dynamic job shop, jobs for processing arrive at different points of times with certain specified inter-arrival times. The jobs may require a certain number of operations to be performed in a particular sequence on specified machines.

The scheduling rule makes use of the attributes of the job such as operation times, due date, number of the operations etc. In order to select the scheduling rule for optimizing the given performance measure, detailed simulation experimentation is required.

2.2 Determine the Experimental Conditions such as Inter-Arrival Time of Jobs, due Date Settings etc.

Data for inter-arrival times and processing times are collected and are shown in table-2. The processing times follow an exponential distribution with a mean equal to 20 minutes. The mean arrival time is 31 minutes.

The Total Work Content (TWK) method of due date setting is used with flow allowance factors of ‘2’, ‘4’ and ‘6’ (represent tight, medium and loose) due-date settings respectively. From the past researches, the TWK method is seen to be superior to other due date setting methods.

In the TWK method, the due-date is determined by

$$D_i = A_i + k\,P_i$$

where

- D_i: due date assigned to the job i,
- A_i: arrival time of job i,
- k : flow allowance factor,
- P_i : total processing time of job i.

The flow allowance factor signifies the extent of time spent by a job in the system.

Assumptions

- A machine can process only one job at a time
- A job, once taken up for processing, should be completed before another job can be taken up, i.e. job preemption is not allowed.
- An operation on any job cannot be performed until all previous operations on the job are completed
- There are no break downs (machines are always available for processing times).
- There are no other limiting resources such as labor and material.

2.3 Identification of Scheduling Rules and Performance Measures

A scheduling rule is used to select a job from among the jobs waiting to be processed at a machine, when the machine becomes free after processing a job. The performance measures evaluated are mean flow time, mean tardiness, percentage of jobs tardy and mean lateness.

2.3.1 Scheduling rules

- Processing time based rules:
  - First-In-First-Out rule (FIFO)
  - Shortest Processing Time rule (SPT)
  - Least Work Remaining rule (LWR) = total remaining process time
  - Average Processing Time rule (APT) = [(total remaining process time) / (No. of operations)]
- Due date based rules:
  - Earliest Due Date rule (EDD)
- Combination Rules:
  - SLACK=[(due date–current time–total remaining processing time)]
  - Slack per Remaining Operation (S/OPN) =[slack/(total remaining Operations)]
  - Critical Ratio (CR) = [(due date – current time) / (total remaining Processing time)]

2.3.2 Performance measures

- Mean flow time $(F) = \frac{1}{n}\sum_{i=1}^{n} F_i$ (1)
- Mean tardiness $(T) = \frac{1}{n}\sum_{i=1}^{n} T_i$ (2)
- Percentage of jobs tardy $P_t = \frac{n_t}{n}100$ (3)

where,

- $F_i = c_i - a_i$
- $Ti = \max(L_i)$
- $L_i = c_i - d_i$
- c_i = completion time of job i.,
- a_i = arrival time of job i.
- d_i = due date of job i.,
- L_i = lateness of job i.,
- n = number of jobs completed,
- F_i = flow time of job i., and
- n_t = number of tardy jobs.

2.4 Development of Simulation Model

A simulation model is developed for the operation of the job shop production system. This simulation model, models the system as it evolves over time in which, system status changes at countable number of points in time. This requires defining the events that can occur and then modeling the logic associated with each event and the corresponding transactions to capture the changing status in the system. The operation of job shop production system is conceptualized as a succession of events occurring on the parts to be processed. The simulation of the system is executed by advancing the occurrence of events in a time ordered sequence. This is achieved by time advance mechanism/event scheduling algorithm. In this approach, the simulation clock is initialized to zero and times of occurrence of future events are determined. The simulation clock is then advanced to the time of occurrence of the most imminent of these future events, at which point the status of the system is updated to account for the fact that an event has occurred and the times of occurrence of future events are also determined. This process is continued until the terminating condition is satisfied.

The initial status of the job shop production system is assumed to be idle and empty. Once an arrival event happens (as per the inter-arrival time distribution), the simulation clock is advanced to the time of occurrence of this event and the attributes with regard to arrived job (number of operations, machine routing, processing times and due-dates etc.) are determined. The machine required for first operation of the arrived job is identified. The job is then processed if the machine is idle, or else waits in the queue. Once, the processing is completed, the queue in front of the machine is checked. If there is no job in front of the machine (i.e., in the queue), the machine is kept idle, otherwise, a job is selected and machine starts processing that job. Once, all the operations of the job are completed, its performance measures are determined and the job leaves the system. After the completion of all the jobs, the simulation process is terminated.

2.4.1 Structure of simulation model

The simulation model developed in Visual C++ consists of number of modules which are listed as follows.

a) Initialization module

The system status and the event lists are initialized. In other words, all the system variables are initialized. The simulation clock is set to zero.

b) Data input module

This module is used to generate the data related to job attributes such as number of operations, inter arrival times and processing times of jobs etc.

c) Timing module

This module determines the next event from the event list and then advances the simulation clock to the time of occurrence of that event. It incorporates the time advance/event scheduling algorithm.

d) Event routines module

The logic associated with each event is coded as a separate function. The event is executed whenever a call is made from the main program. The following are the two major events that characterize the operation of the system.

- Arrival of a job to the shop
- Departure of a job from a machine.

e) Scheduling rules module

The scheduling rules considered in the present study are coded as separate functions. Whenever a particular scheduling rule is required for simulation experimentation, the corresponding function is called so as to execute the scheduling decision.

f) Report module

This module computes the output performance measures such as mean flow time, mean tardiness, percentage of tardy jobs and mean lateness at the end of the simulation.

g) Main program

The main program invokes the timing module to determine the next event and then transfers the control to the corresponding event function to update the system status appropriately. The main program checks for the termination and invokes the report generator when the simulation is completed.

The flowcharts for main simulation model, part arrival event, part departure event are shown in Fig.-1, Fig.-2 and Fig.-3.

2.4.2 System configuration

Each job consists of a specific set of operations, which are to be processed according to a given technical precedence order. The level of an operation $O_{i,j}$, that is, the sequence of $O_{i,j}$ in a job 'j' is defined by 'i'. Each operation $O_{i,j}$ is described by the prescribed machine 'm' and processing time 't'. The JSS optimization problem determines the optimal schedule that specifies the operation sequence on machines (i.e., which machines are to process which jobs and when) in order to ensure optimum value of a given criterion.

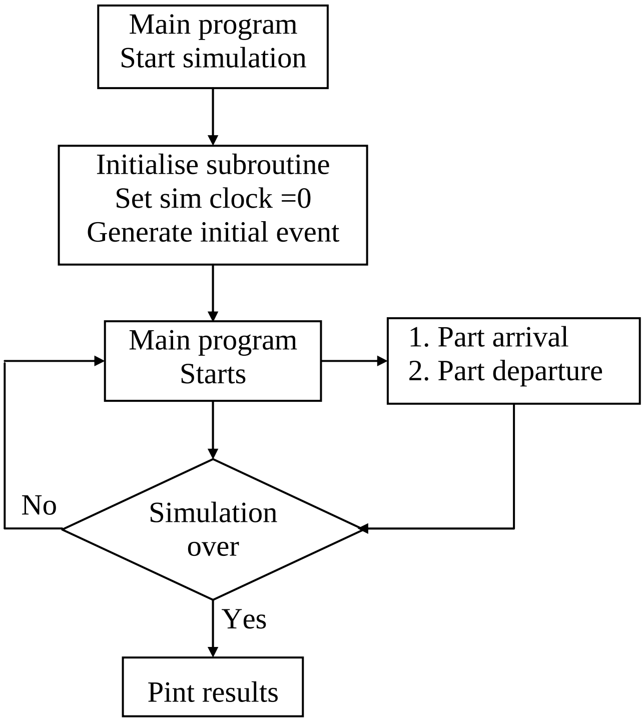

Fig. 1 Flow chart for simulation model

In the present study, a job shop where the job is randomly assigned through the machines was

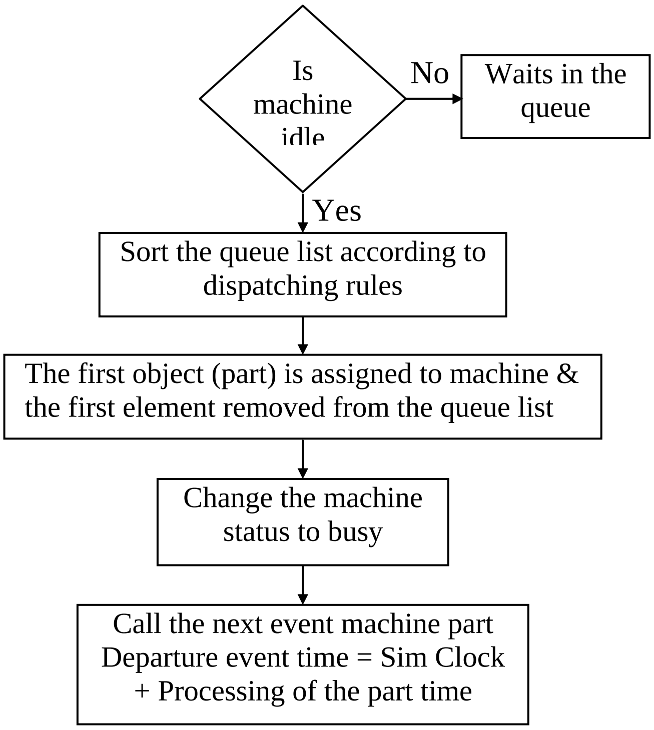

Fig. 2 Flow chart for part arrival

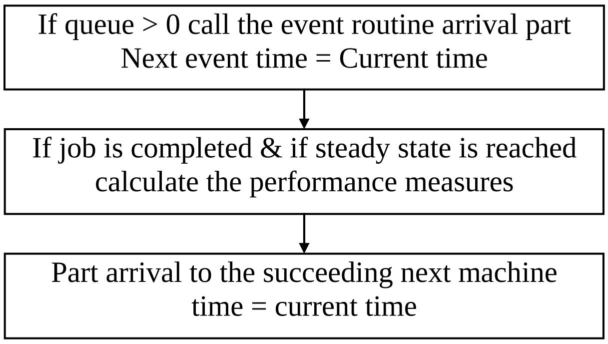

Fig. 3 Flow chart for part departure

considered for the study. When a job leaves a machine and proceeds to another, it is equally likely to require any one of the machines. By this process, an allotment procedure is established which does not include a machine for allotment more than once.

Simulation experiments have been conducted for a combination of two sets of mean inter arrival times, i.e., 30 and 35 and three due date setting factors, i.e., 2, 4, 6 for eight scheduling rules .

2.5 Comparison of Mean Flow Time (minutes)

'SPT' rule with tight, medium and loose due date settings provides the smallest value of mean flow time for both arrival times. Further, 'LWR' and 'APT' provide the next smallest values of the mean flow time for both arrival patterns under all due date settings.

	Experiments					
Scheduling Rule	1 30-2	2 30-4	3 30-6	4 35-2	5 35-4	6 35-6
EDD	36.00	30.40	28.18	59.58	55.78	53.74
SPT	**19.24**	**19.24**	**19.24**	**27.77**	**27.77**	**27.77**
LWR	27.38	27.38	27.38	29.15	29.15	29.15
SLACK	29.83	26.47	29.52	46.67	44.90	42.95
FCFS	36.76	41.69	41.76	52.96	57.03	62.68
CR	36.98	36.78	41.93	49.94	58.18	59.63
APT	26.92	26.92	26.92	30.30	30.30	30.30
SLACK/N	33.14	30.94	31.59	61.62	52.39	108.82

2.6 Comparison of Mean Tardiness (minutes)

'EDD' rule provides better results under loose due date setting with inter-arrival time of 30. 'SPT' rule provides better results under all due date settings with both arrival time patterns. 'LWR', 'APT' rules come next.

	Experiments					
Scheduling Rule	1 30-2	2 30-4	3 30-6	4 35-2	5 35-4	6 35-6
EDD	26.57	11.77	**2.77**	50.10	36.27	24.48
SPT	**9.97**	**5.46**	3.61	**18.17**	**11.43**	**7.94**
LWR	17.67	11.90	8.78	19.87	13.62	9.87
SLACK	20.06	8.88	6.61	36.80	25.72	17.42

FCFS	27.49	25.87	21.00	43.37	38.80	37.88
CR	27.99	19.93	20.21	40.49	40.03	34.83
APT	17.13	10.93	7.77	21.02	14.70	11.54
SLACK/N	23.59	15.02	11.28	51.50	34.94	82.55

2.7 Comparison of Percentage of Tardy Jobs

For inter-arrival pattern of '30', 'SPT' rule provides better results for all due date conditions. 'LWR' rule provides better result under tight and loose due date setting for arrival pattern '35'. APT rule performs well under due date setting of '4' for arrival pattern '35'.

	Experiments					
Scheduling Rule	1 30-2	2 30-4	3 30-6	4 35-2	5 35-4	6 35-6
EDD	49.78	41.3	25.00	50.8	50.4	49.34
SPT	**36.74**	**12.61**	**5.87**	46.30	21.74	10.44
LWR	39.57	15.22	8.48	**41.09**	21.30	**10.43**
SLACK	46.96	30.22	13.26	50.43	43.69	29.57
FCFS	40.65	31.96	25.65	49.35	42.39	36.52
CR	43.04	33.26	25.43	49.57	43.04	35.65
APT	40.65	16.30	8.26	43.26	**19.35**	11.09
SLACK/N	44.57	31.09	23.26	50.00	41.30	42.39

2.8 Comparison of Mean Lateness (minutes)

For all due date settings considered, 'SPT' and 'LWR' rules provides better results for both arrival patterns.

	Experiments					
Scheduling Rule	1 30-2	2 30-4	3 30-6	4 35-2	5 35-4	6 35-6
EDD	26.53	10.88	-1.94	50.09	36.18	24.30
SPT	**9.37**	**-0.495**	**-10.36**	**18.05**	**8.33**	**-1.40**
LWR	17.27	7.16	-2.96	19.58	10.00	0.44
SLACK	19.86	6.84	-0.378	36.78	25.12	13.70
FCFS	27.03	22.17	12.48	43.30	37.49	33.56
CR	27.54	16.98	12.15	40.41	38.73	30.73
APT	16.83	6.74	-3.35	20.82	11.33	1.85
SLACK/N	23.29	11.66	2.58	51.45	33.60	80.23

2.9 Results (better scheduling rules under given conditions)

From the results it was found that the

- 'SPT' rule performs well under all inter-arrival due date settings and inter-arrival times.
- 'EDD' rule gives better performance for mean tardiness under loose due date setting with inter-arrival time of '30'.
- 'LWR' rule gives better performance for percentage jobs tardy for due date settings of '2,6' with inter-arrival time of '35' while APT rule gives better performance for percentage jobs tardy for due date setting of '4' with inter-arrival time of '35'.

Performance measures	30-2	30-4	30-6	35-2	35-4	35-6
Mean flow time	SPT	SPT	SPT	SPT	SPT	SPT
Mean tardiness	SPT	SPT	EDD	SPT	SPT	SPT
Percentage jobs tardy	SPT	SPT	SPT	LWR	APT	LWR
Mean lateness	SPT	SPT	SPT	SPT	SPT	SPT

3 Conclusions

The present work deals with simulation based experimentation of the dynamic job shop scheduling problem. A number of scheduling rules have been considered for the purpose of investigation. Performance measurements have been taken for analyzing best scheduling criteria. For each scheduling rule, a set of six experiments have been conducted. These experiments differ with respect to 'Due Date Setting Factor and the Mean Value of the Inter-Arrival Time'. The performance measures evaluated are mean flow time, mean tardiness, percentage of tardy jobs and mean lateness. The simulation output has been analyzed statistically.

SPT provides consistent results for flow time and percentage of tardy jobs. However, the performance of LWR is comparable with SPT under most job shop conditions.

Among the other rules, for mean tardiness and percentage of tardy jobs, APT, shows better results.

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Table-1
Pilot and random study on general shift machines

Machine No.	Machine description	Pilot Study		No. of Observations	Random Study	
		% working	% idle		% working	% idle
38A	Plano milling machine.	45	55	396	42	58
22A	Radial Drilling Machine	12	88	169	15	85
14A	Medium Duty Lathes	30	70	336	30	70
14B	Medium Duty Lathes	35	65	364	35	65
14D	Medium Duty Lathes	43	57	393	47	53
28A	Plano milling machine	33	67	354	33	67
28B	Plano milling machine	40	60	384	40	60
33B	Universal Milling machine	35	65	364	38	62
33C	Universal Milling machine	26	74	308	26	74
46	Gear Hobbing machine	79	21	266	83	17
16I	Light Duty Lathes	21	79	266	21	79
16J	Light Duty Lathes	31	69	343	35	65
16K	Light Duty Lathes	21	79	266	21	79
16P	Light Duty Lathes	25	75	300	30	70
16R	Light Duty Lathes	34	66	359	37	63
16O	Light Duty Lathes	23	77	284	23	77
23A	Column Drill	42	58	390	40	60
22E	Radial Drill	30	70	336	30	70

Table-2
Arrival and Processing times of jobs

S.No.	Work order No.	Description	Date of arrival	Time of arrival	Arrival pattern (min)	Processing times (min)
1	BF-333	Flange coupling of Auxiliary Hoist	02-02-2006	9:33 AM	33	22
2	BF-1041	Coupling for M-41 Fan	02-02-2006	10;02 AM	29	24
3	BF-1079	Worm Shaft (POS-7)	02-02-2006	10:35 AM	33	23
4	BF-1080	Worm Shaft (POS-6)	02-02-2006	11:06 AM	31	19
5	BF-1091	KA-1 Through G/Box input pinion shaft	02-02-2006	11:36 AM	30	18
6	MMSM-109	Driving Axle for D710 Wheel	02-02-2006	12:07 AM	31	21
7	MMSM-475	Turbine Shaft Repair	02-02-2006	12:39 AM	32	23
8	CCCD-904	Repair of conveyer pulleys	02-02-2006	01:11 PM	30	20
9	CRMP-280	Modified extended Tongue (Left)	02-02-2006	01:41 PM	30	15
10	EMD-183	DN600 Sliphon Flange	02-02-2006	02:12 PM	31	17
11	ENMD-299	Motor side coupling	02-02-2006	02:43 PM	31	18
12	ENMD-300	Pump side coupling	02-02-2006	03:15 PM	32	20
13	ENMD-175	Shaft for Impeller Fan DE-11.1	02-02-2006	03:47 PM	32	21
14	ESF-149	Hammer Pallets Machining	02-02-2006	04:18 PM	31	15
15	ESF-300	Machining of power hack saw drive wheel	02-02-2006	04:48 PM	30	20
16	LMMM-195	Hub For U Shaft of BV5	03-02-2006	9:32 AM	32	17
17	LMMM-737	Liner for Modified Base Frame	03-02-2006	10:04 AM	32	19
18	RMHP-1003	Machining of Bore for Body Structure	03-02-2006	10:36 AM	31	17
19	RMHP-1004	Manufacturing Sleeve for Bogie	03-02-2006	11:07 AM	31	18
20	RMHP-1005	Manufacturing Distance piece for Bogie	03-02-2006	11:37 AM	30	26
				Total	**622**	**393**
				Mean	**31.1**	**19.65**