Scheduling job shop – *A case study*

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**Abstract.** The scheduling in job shop is important for efficient utilization of machines in the manufacturing industry. There are number of algorithms available for scheduling of jobs which depend on machines tools, indirect consumables and jobs which are to be processed. In this paper a case study is presented for scheduling of jobs when parts are treated on available machines. Through time and motion study setup time and operation time are measured as total processing time for variety of products having different manufacturing processes. Based on due dates different level of priority are assigned to the jobs and the jobs are scheduled on the basis of priority. In view of the measured processing time, the times for processing of some new jobs are estimated and for efficient utilization of the machines available an algorithm is proposed and validated.

1. **Introduction**

In manufacturing industries discrete products are manufactured through processing of raw materials on different machines. Different methodologies are used to organize the processing of jobs in different industries. The ideal handling areas are known as job shop, cellular manufacturing, project shop, continuous manufacturing, flow line, flexible manufacturing and reconfigurable manufacturing systems. The efficient use of the manufacturing facility depends upon the proper scheduling of jobs which is dependent upon product’s nature, its lot size, the transfer of energy and material and implementation of intangible functions like production planning, process planning, inventory control and supply chain management. The scheduling of jobs in industries is mostly done by experienced workers with pen, paper and graphical approach and also through some industrial databases [1-3]. For immediate solution of problems, simple dispatching rules are typically used like sequencing at a level of work center [2-3]. This can create confusions in scheduling, where it is difficult to predict the completion dates, also some time the jobs with higher priority are chased down by the management [4].

Many rules are found in literature for scheduling of jobs based on due dates, criticality of operation, processing time, and resource utilization and critical ratio [5]. The ratio of processing time of a job and its due date is known as critical ratio. Rules on the basis of processing time are shortest processing time (SPT) and longest processing time (LPT). The jobs having shorter time are processed first in SPT, while the jobs having longer time are processed first in the LPT. The jobs having earlier due dates are processed first in due date. The other dispatching rules are first come first serve (FCFS) where the jobs are processed in their incoming order and last come first serve (LCFS) where the last jobs are first processed [6].
In manufacturing industries single machine scheduling, flow shop scheduling and job shop scheduling are most famous. In single machine all jobs are processed on a single machine and for best results the jobs are scheduled in ascending order of time. In flow shop every job must be processed through each machine and the processing time for each job is different on every machine. In flow shop the jobs are arranged in different orders and the best order is picked for which the completion time for a single batch is minimum. In job shop each job may or may not be processed on all machines and also the time of processing of each job is different in different machine. It is one of the most complex problem and optimum scheduling is also hard to calculate [7]. For ideal scheduling of job shop many algorithms have been developed from time to time [7-9].

A job shop typically consists of machines with identical material processing capabilities. The scheduling problem aims to sequence the manufacturing decisions with low volume, high variety systems where the route for one part is fixed while it vary from part to part [10]. For instance, in a specific case involving 10 jobs and 10 machines posed by Muth and Thompson [12] in 1963 was stayed unsolved for 20 years, until it was solved by Carlier and Pinson [13] in 1985.

Neural network for JSPs was first time applied by Takefuji [14]. Later on different neural architectures had developed and applied successfully to solve JSP [15-17]. Genetic algorithms are developed and used for job shop scheduling [18-19].

Many heuristic methods have also been developed for job shop problems. Well known are Johnson [20], Gupta [21], bottle neck [22], Palmer [23] branch and bound [24] etc. With the passage of time these methods were improved further but modifications are still needed. The major problem with these techniques are that some are based on processing time ignoring the due date while other considers the due date and ignoring the processing time.

This research intends to develop a new algorithm for job shop problem, considering the jobs having multiple machine operations with corresponding due dates, hence accounting for lead time.

2. The problem formulation

Consider a typical job shop with n jobs and m machines. Each job will be processed through one machine only once, and it is not necessary that all jobs will be processed through all machines. Every job will be having a particular order of processing. The processing time for each job is fixed and known. [25]

To schedule jobs the following parameters have to be identified first:

I. The available facility on shop floor.
II. Total jobs in system.
III. Setup and operation time for each job on each machines.
IV. Time to complete all jobs.

After identification of the parameters the scheduling of the jobs is performed on the basis of following constraints.

I. Every job will be processed through respective machines (j = 1, 2, 3, ….. m).
II. One machine can process single job at a time.
III. The time for setup for different operations are not dependent of the sequence
IV. The setup times for different operations are independent of the sequences and are incorporated in processing time.
V. The scheduling of jobs will be done on priority basis (due dates). Jobs will be assigned with three levels of priority. Priority 1 being the Top priority, priority 2 being the medium priority and priority 3 the lowest priority. The top priority jobs will be scheduled first and the lowest priority at the last.
3. Analysis of the manufacturing facility and the jobs processing

The manufacturing facility is analyzed through the availability of machines and respective operations to be performed on each machine. On similarity basis the manufacturing facility is divided into Shaper (S), Lathe (L), Milling (M), Boring (B), Welding (W), and Grinding (G) machine centres.

After analysing the facility, jobs to be processed are selected. The operation time for each job on each machine center observed through time motion study with a stop watch and the operation is performed by the best worker.

Table 1 displays the order of operations and processing time for individual jobs on respective machine centers with their order of priority.

| Job Name         | Jobs No | S      | L      | M      | B      | W      | G      | Priority |
|------------------|---------|--------|--------|--------|--------|--------|--------|----------|
| Nut              | 1       | 0      | 17     | 0      | 0      | 0      | 0      | 2        |
| Bolt             | 2       | 0      | 19.5   | 0      | 0      | 0      | 0      | 2        |
| Gear             | 3       | 60     | 18.5   | 30     | 15     | 0      | 4      | 1        |
| Hexagonal Gear   | 4       | 65     | 17.5   | 45     | 4      | 0      | 6      | 1        |
| Flange Pipe      | 5       | 0      | 50     | 35     | 35     | 27     | 25     | 2        |
| Screw            | 6       | 62     | 58     | 15     | 0      | 0      | 0      | 1        |
| Lead Screw       | 7       | 60     | 34.5   | 20     | 0      | 0      | 0      | 2        |
| Universal Coupling | 8   | 60     | 17.5   | 20     | 10     | 0      | 6      | 3        |
| Lathe Center     | 9       | 63     | 29.5   | 0      | 0      | 5      | 3      |          |
| Piston Connecting| 10      | 0      | 0      | 17     | 11     | 0      | 7      | 3        |
| Rod              |         |        |        |        |        |        |        |          |
| Sprocket         | 11      | 0      | 0      | 15     | 55     | 0      | 5      | 2        |
| Tie Rod End      | 12      | 0      | 26     | 27.5   | 27     | 0      | 6.5    | 3        |
| Gear Pump Flange | 13      | 0      | 27     | 15     | 31     | 17     | 5      | 3        |

4. The Solution Methodology

In the proposed algorithm the jobs are scheduled on the basis of priority. The algorithm is described as following flow chart: Figure 1

**Figure 1. Algorithm flow chart**
5. Results and discussions

In order to check that proposed heuristic give optimal results different well known heuristics of job shop scheduling is applied to 13 jobs and 6 machines problem in Table 1. The result obtained by applying various heuristics are shown in Table 2 with calculated sequence and total make span.

| Algorithm | Sequence | Make Span (Minutes) |
|-----------|----------|---------------------|
| SPT       | 1 2 10 11 12 13 9 8 7 3 6 4 5 | 559.5 |
| LPT       | 5 4 6 3 7 8 9 13 12 11 10 2 1 | 580 |
| Johnsons  | 1 2 10 11 12 13 5 6 4 3 7 8 9 | 404.5 |
| Gupta     | 1 2 10 11 12 13 5 6 4 3 7 8 9 | 404.5 |
| CDS       | 1 2 11 13 12 10 8 4 5 9 3 6 7 | 424.5 |
| Palmer    | 11 5 10 13 12 1 2 8 3 9 4 7 6 | 443 |
| WI        | 10 5 12 11 13 1 2 6 3 4 7 8 9 | 404.5 |

The comparison of different heuristics in Table 2 shows that WI method can give optimal results, which is comparable to well-known heuristic techniques like Johnson, Gupta, Palmer, and CDS. Effect of Lead time is neglected for the sequences acquired based on different algorithm in Table 2. Therefore this study is intended to achieve optimal sequence by considering the lead time as well as processing time.

Now considering the lead time, the steps discussed in solution methodology are used. Jobs with lead time of one day are given prime importance compare to jobs having lead time of 2 and 3 days. So first take the jobs having lead time of “1 day”, calculate their WI and arrange it in ascending order of WI value. Similarly apply same procedure to group “2” and “3” as shown in combine form in Table 3:

| Machines/Jobs | S | L | M | B | W | G | Lead Time | WI |
|---------------|---|---|---|---|---|---|-----------|----|
| 6             | 62| 58| 15| 0 | 0 | 0 | 1         | 0.849315 |
| 3             | 60| 18.5| 30| 15| 0 | 4 | 1         | 0.88189  |
| 4             | 65| 17.5| 45| 4 | 0 | 6 | 1         | 0.887218 |
| 5             | 0 | 50| 35| 35| 27| 25| 2         | -0.13605 |
| 1             | 0 | 17| 0 | 0 | 0 | 0 | 2         | 0.058824 |
| 7             | 60| 34.5| 20| 0 | 0 | 0 | 2         | 0.061135 |
| 11            | 0 | 0 | 15| 55| 0 | 5 | 2         | 0.085714 |
| 2             | 0 | 19.5| 0 | 0 | 0 | 0 | 2         | 0.102564 |
| 10            | 0 | 0 | 17| 11| 0 | 7 | 3         | -0.25    |
| 12            | 0 | 26| 27.5| 27| 0 | 6.5| 3      | -0.08075 |
| 13            | 0 | 27| 15| 31| 17| 5 | 3         | -0.05556 |
| 8             | 60| 17.5| 20| 10| 0 | 6 | 3         | 1.136842 |
| 9             | 63| 29.5| 0 | 0 | 0 | 5 | 3         | 1.966102 |

Make span calculated for the schedule obtained in Table 3 is 498 minutes. By matching the results to, LPT, SPT, Gupta, Palmer, and Johnson rule it gives optimum results as shown in Table 4. If the priority of the jobs were changed the total makeup span will also vary.
Table 4. Comparison of results obtained from various algorithms

| Algorithms | Total Make Span (Minutes) |
|------------|--------------------------|
| SPT        | 503.5                    |
| LPT        | 525                      |
| Johnson    | 503.5                    |
| Gupta      | 503.5                    |
| CDS        | 522                      |
| Palmer     | 510                      |
| WI         | 498                      |

The improved technique separates jobs based on lead time. Jobs with shorter lead time are scheduled first and the sequence is obtained by computing WI method. Similarly the jobs with medium lead time are arranged after shorter lead time jobs and their sequence is achieved by WI method. Lastly the jobs with long lead time are arranged after medium lead time and their sequence is achieved using WI method. Thus a new optimal sequence is obtained by considering the lead time.

Processing time is estimated for new products based on available data. So a new problem having 6 jobs and 6 machines is created with their desired lead time. The purpose of it is to check whether the new heuristic give optimal result by applying it to other set of problem or not. The results are presented in Table 5:

Table 5. Processing time with priorities for new jobs

| Machines / New Jobs | S | L | M | B | W | G | Priority |
|---------------------|---|---|---|---|---|---|----------|
| P1                  | 65| 10| 0 | 0 | 5 | 0 | 1        |
| P2                  | 0 | 65| 60| 55| 0 | 20| 2        |
| P3                  | 85| 60| 40| 60| 25| 0 | 3        |
| P4                  | 80| 55| 30| 20| 0 | 20| 3        |
| P5                  | 80| 20| 30| 10| 10| 0 | 2        |
| P6                  | 65| 15| 0 | 20| 10| 0 | 1        |

Neglecting lead time effect make span is calculated based on SPT, LPT, Johnson, Gupta, CDS, Palmer, heuristic as shown in Table 6:

Table 6. Comparison of algorithms

| Algorithm | Sequence | Make Span |
|-----------|----------|-----------|
| SPT       | P1 P6 P5 P2 P4 P3 | 560       |
| LPT       | P3 P4 P2 P5 P6 P1 | 435       |
| Johnsons  | P2 P3 P4 P5 P6 P1 | 390       |
| Gupta     | P2 P3 P4 P5 P6 P1 | 390       |
| CDS       | P2 P6 P5 P1 P6 P3 | 545       |
| Palmer    | P3 P4 P5 P1 P6 P2 | 560       |
| WI        | P2 P3 P4 P5 P6 P1 | 390       |

As shown in Table 6 the make span calculated based on WI method give optimal result, comparable to Johnson and Gupta heuristic.
Now considering the lead time, apply the steps discussed in methodology section to get optimal sequence. The Table 7 shows optimal sequence of jobs on available machines:

| Machines / Jobs | S  | L  | M  | B  | W  | G  | Priority | WI    |
|-----------------|----|----|----|----|----|----|----------|-------|
| P6              | 65 | 15 | 0  | 20 | 10 | 0  | 1        | 1.444444|
| P1              | 65 | 10 | 0  | 0  | 5  | 0  | 1        | 4.333333|
| P2              | 0  | 65 | 60 | 55 | 0  | 20 | 2        | -0.11111|
| P5              | 80 | 20 | 30 | 0  | 10 | 10 | 2        | 1.166667|
| P3              | 85 | 60 | 40 | 60 | 25 | 0  | 3        | 0.459459|
| P4              | 80 | 55 | 30 | 20 | 0  | 20 | 3        | 0.571429|

Make span calculated is 500 minutes for sequence obtained based on WI method. The comparison of WI to other algorithms is shown in Table 8:

| Algorithms | Total Make Span (Minutes) |
|------------|---------------------------|
| SPT        | 560                       |
| LPT        | 500                       |
| Johnson    | 505                       |
| Gupta      | 550                       |
| CDS        | 500                       |
| Palmer     | 560                       |
| WI         | 500                       |

6. Conclusion

Scheduling techniques namely LPT, SPT, Johnson, Gupta and Palmer are studied for job shop scheduling. A new heuristic “weighted index (WI)” method is developed which give optimal results comparable to these four techniques. The new WI method is easy and has less computational cost compared to other heuristics. New heuristic and other four heuristic are improved by addition of assumption. The assumption is based on grouping of jobs based on lead time. The earlier methods were completely based on processing time ignoring the aspect of lead time. These new modified methods include both processing time and lead time aspects.

7. References

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