DEVELOPMENT OF AN ARENA SIMULATION MODEL FOR SCHEDULING PROBLEMS IN JOB SHOP PRODUCTION

Md Kamrul Islam, Tanmoy Palit and *Abul Mukid Mohammad Mukaddes

Department of Industrial and Production Engineering, SUST
E-mail: mukaddes1975@gmail.com.

Abstract

The job-shop scheduling problem (JSSP) is one of the most concerning issues in this modern manufacturing world, as it is extremely challenging both theoretically and practically. The use of dispatching rules can be a good solution for JSSP. This paper represents a simulation approach to solve the scheduling problem in a real-life job-shop production unit. The study includes the development of a model based on Arena simulation software, by which a job-shop production environment can be simulated, and different dispatching rules can be compared to find the most optimal solution of the job shop scheduling problem. A case study was conducted in a manufacturing workshop where job-shop scheduling problems are acute as no scheduling methods are applied. The study aims at reducing the total makespan of the job-shop production workshop by having optimum utilization of limited resources. Some common dispatching rules were experimented in the simulation model and found FIFO to perform best in this problem.

Keywords: Job shop, scheduling, dispatching rules, simulation, Arena, makespan

1. Introduction

Scheduling of operations is considered the most critical issues in the manufacturing processes management and planning. It is concerned with jobs assignment to production resources and specifying the sequence to optimize certain objective functions. In a manufacturing environment, scheduling depends on the environment of the shop floor such as job-shop, flow-shop and open-shop [1]. But job shop scheduling problems are considered a good representation of the general domain and has earned a reputation for being notoriously difficult to solve. The job shop scheduling problem (JSSP) is extremely challenging both in theory and in practice. Because so many parameters need to be considered when scheduling production [2]. Simulation is one of the powerful tools for testing the efficiencies of different scheduling policies. It can simulate a long period in real life within a reasonably short computer running time of several seconds or minutes. This saves many long-time observation costs. Moreover, simulation can help to get the result of future time without any real change to machine layout or the number of machines [3].

Scheduling of job shops has been extensively researched over the last five decades and it continues to attract the interests of both academic researchers and practitioners. The complexity of the scheduling process in job shops, especially when multiple routings and assembly operations are considered, has a significant theoretical attraction for research in this area. Panwalkar and Iskander divided the scheduling studies into the following two categories:

- Theoretical research dealing with optimization procedures.
- Experimental research dealing with dispatching rules.

The theoretical research has aimed at developing mathematical models and optimal or sub-optimal algorithms. And the experimental research has been primarily concerned with priority dispatching rules and heuristics that can efficiently solve the scheduling problem [4].

Reference [2] represents a case study that was conducted on a metal Industry located in Ethiopia. In metal and engineering company was facing a job shop scheduling problem in its spare part manufacturing plant. The higher makespan (lead-time) to produce parts resulted from conventional scheduling was dissatisfying customers and causing low machine utilization. That study aimed at reducing makespan and improving the performance of the manufacturing system.

Reference [5] represents a simulation study of dispatching rules in a stochastic job shop dynamic scheduling that considers random job arrivals and stochastic processing times. The computational simulation was employed to study the effects of some widely used dispatching rules in the performance of job shop manufacturing environment, concerning the makespan, the total tardiness and the number of tardy jobs.

Reference [6] represents the importance of dispatching rules in improving the performance of a factory. The study evaluates some dispatching rules with the classification of hybrid and single rules. The authors compared the
performances of various single & hybrid dispatching rules and ranked among themselves by a 12-point system to declare the best one.

Generally, the job shop institutes in our country face a lot of problems due to not maintaining any scheduling methods in their production facilities. To solve the problems generated from not using any scheduling methods, a model of a job shop production facility has been developed in Arena simulation software. Then some products having the same types of operating processes had been selected and determined as sample parts. These sample parts were then being manufactured in a job shop production unit. The unit does not maintain any scheduling methods, so it is continuously challenged by scheduling problems. Jobs were assigned in a random selection that results in higher makespan and lower resource utilization. Observing the operations, the processing times of each process of all parts were measured. This study aims to reduce the total processing time of the four sample parts by comparing various rules of scheduling. To do so, different methods of job shop scheduling were analyzed through the Arena model to compare their performances and thus, tried to get the best scheduling method for this problem. In this paper, four jobs requiring seven processes with specific processing sequences arriving at a specific time are considered and through the Arena model, tried to solve the job shop scheduling problem.

2. Materials and methodology

2.1 Job shop production scheduling

A job shop is a type of manufacturing process structure where small batches of a variety of custom products are made. It is a small company or business that makes specific products for one customer at a time. It deals in customization and relatively small production runs, not volume and standardization. This type of business only produces specific goods when it receives an order for them.

Job shop scheduling is an optimization problem in computer science and operations research in which jobs are assigned to resources at particular times. The objective when solving or optimizing this general problem is to determine the schedule which minimizes the makespan [7].

Priority dispatching rules are the most widely used for solving JSSP where all the operations available to be scheduled are assigned a priority. The operation with the highest priority is chosen to be sequenced first [8]. A priority dispatching rule is a simple mathematical formula that, based on some processing parameters, specifies the priority of operations to be executed. The priority dispatching rules that have been checked and analyzed in this paper are given in table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Rule</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FIFO</td>
<td>First In First Out Priority is given to the first piece that is input, which must be first to be output.</td>
</tr>
<tr>
<td>2</td>
<td>LIFO</td>
<td>Last In First Out Priority is given to the last piece that is input, which must be first to be output.</td>
</tr>
<tr>
<td>3</td>
<td>EDD</td>
<td>Earliest Due Date Priority is given to the fulfillment of the most urgent orders in terms of delivery deadline.</td>
</tr>
<tr>
<td>4</td>
<td>SPT</td>
<td>Shortest Processing Time Priority is given to the shortest individual processing time of the jobs.</td>
</tr>
<tr>
<td>5</td>
<td>LPT</td>
<td>Longest Processing Time Priority is given to the longest individual processing time of the jobs.</td>
</tr>
</tbody>
</table>

2.2 Steps involved in the study

Several steps had been followed to conduct the study. The steps to complete this study are:

Step 1: Idea generation- First the variables affecting the scheduling problems such as the processing time to complete a single process, the due date of the complete product was identified. Simulation modeling was used here to simulate a real scenario that faces the same type of problem. Arena simulation software was used here because it seemed to suit best for creating a replica of the existing scenario.

Step 2: Preliminary investigation through literature- A complete literature survey had been conducted to know whether a similar type of researches had been done or not. The progression of this study was done relying upon a similar kind of researches but a new way to compare the dispatching rules were always tried.

Step 3: Develop a preliminary JSSP solution model on Arena simulation- To start this study, a model was needed that can be useful to check whether complete information of a job shop production can be fed and checked to compare among various dispatching rules. So, a model had been developed on Arena.

Step 4: Verify the JSSP solution model with secondary data- A routing matrix of a job shop production system is found in reference [2],[9] and the data was inputted on the model. After finding the results, the results were matched with Gantt chart for the secondary data. By this way, the model was verified.
Step 5: Determine and manufacture sample parts - Four sample parts were prepared in a workshop that has multiple machines to produce different products with similar types of operations but in a different sequencing manner. By observing every process of all the final products, their processing times were found and recorded.

Step 6: Develop the final JSSP solution model - The final model was developed on Arena simulation software based on the previous model with some extensions and modifications. The various modules of Arena were set so that various dispatching rules could be checked. The parameters on which the final comparison would take place were selected and were set on the model.

Step 7: Validate the JSSP solution model with primary data - Developing a model needs to be ensured whether it can represent the original system perfectly. The makespan was measured from the model and checked by creating a Gantt chart of the scheduling problem manually. When the results had an approximate match, the model was ensured to be valid.

Step 8: Analyze the output result & find an optimal solution - The complete results were found from the output and all the parameters gave valid results that can be used to compare all the dispatching rules. With the comparison, the optimal solution is easily calculated and the best approach to conduct job shop scheduling was found.

2.3 Problem statement
Before developing the final Arena simulation model, the sample parts were prepared that required almost the same types of processes in the same types of machines to be manufactured but in different sequences. These products are: bolt (J1), nut (J2), gear (J3) and plug (J4). The processes for preparing the sample parts are: turning (P1), threading (P2), drilling (P3), cutting off (P4), grinding (P5), milling (P6) and finishing (P7). Although these seven processes cover all the operations to prepare these parts, the sequences of the processes are different. The material for preparing sample parts was mild steel. The data was collected by the sequential operations of these four specific jobs in a workshop named S.K. Enterprise & Engineering works located at Shimultala, Jamgora, Ashulia, Dhaka-1349. The data found by observing the manufacture of these products are recorded and then the data was fed into the developed JSSP solution model. Table 2 shows the routing matrix that was formed after collecting the data.

<table>
<thead>
<tr>
<th>Jobs</th>
<th>Job processing sequence (processing time in minutes)</th>
<th>Total processing time (minutes)</th>
<th>Due date (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>P1 (3) P2 (10) P4 (2) P5 (6) P7 (2)</td>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td>J2</td>
<td>P1 (2) P3 (2) P5 (6) P4 (2) P2 (7) P7 (2)</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>J3</td>
<td>P1 (10) P5 (2) P6 (20) P4 (2) P3 (2) P7 (3)</td>
<td>39</td>
<td>6</td>
</tr>
<tr>
<td>J4</td>
<td>P1 (3) P2 (10) P3 (2) P4 (2) P5 (6) P7 (2)</td>
<td>25</td>
<td>1</td>
</tr>
</tbody>
</table>

3. Model development
Before developing the Arena model, a conceptual model was developed. It was developed in a way that it can be a representation of an existing system of job shop production that would help people understand the proposed model easily. To develop the conceptual model, entity-relationship modeling (ERM) technique was used. The main components of the conceptual model represent the entities and relationships. The entities represent independent functions. The relationships are responsible for relating the entities to one another. To form the JSSP solution model, the relationships have combined with entities and attributes to further describe the model. Fig. 1 shows the JSSP solution model developed in Arena software.

The model starts with four “Create modules”, where the ordered products are placed as entities. In each “Create/Entity module”, the information of a single product is stored. These entities then leave the module to begin processing through the system. The entity type is specified in this module. Then in the “Advanced Set module”, the sequence set is assigned which has been linked with “Sequence module”, where the machining sequence and the machining process times are assigned. The attributes of the entities like entity picture, entity sequence, due dates of each order are assigned in the “Assign module”. The dispatching rules are assigned in the “Queue module”. The entities are then sent to “Route modules”. For each entity, one “Route module” is placed in that module, the destination type is set as “By Sequence”. So, the next destination of the entity would be in a sequenced manner that had been assigned in the “Sequence module” before.
The “Route module” then sends the entity to the first station in line by the machining sequence. Seven “Station modules” have been placed, one for each operation processes. Each of the stations receives the entities and sends them to the “Process module” linked with them. So, seven “Process modules” are set up for the seven operation processes. After completing the process, the entities are sent to the “Route module” again, which determines the next process to be done and sends the entities to the next station. When all the operation processes of an entity are completed, the “Route module” sends them to the inventory station.

The “Record module” has been set up for recording outputs. In the “Time Persistent module”, the report labels are set and the expressions for statistical analysis of the report labels are denoted.

Several performance measures used to evaluate which alternative performs well in an observed system. The performance measuring parameters are:

1. Makespan: The makespan is the total length of the schedule (that is, when all the jobs have finished processing). One of the common objectives in job shop scheduling is to minimize the makespan.

2. Overall utilization: Overall utilization is the total number of units currently scheduled in a resource set. This variable returns the total number of units currently scheduled for all resource members of the specified set.

3. System average queue length: Queue length is the number of parts that are waiting in the machine queue.

4. System average queue waiting time: Queue waiting time is the time that a part spent waiting in the machine queue.

5. System average WIP (Work in process): It is the average number of jobs in the system. The relationship between the number of jobs in the system and the WIP inventory is that when there are a greater number of jobs in the system, the WIP inventory will be high.

4. Verification and validation

To validate the model here, the data was fed into the model. Then the model was run with different scheduling rule and the makespan for the rules were recorded. Then the Gantt chart was prepared.

The makespan for FIFO in Arena and the makespan found by the Gantt chart are:

Fig. 1. Arena model for JSSP solution

Fig. 2. Makespan (FIFO) from Arena simulation

Fig. 3. Makespan (FIFO) from Gantt chart

Arena (45 minutes). To eliminate any confusion, another dispatching rule (SPT) was checked.

The makespan for SPT in Arena and the makespan found by the Gantt chart are:
by Arena. Both of the tests definitely indicate that the model is valid and verified.

5. Result and discussion

From the parameters for five dispatching rules (FIFO, LIFO, SPT, LPT, and EDD) scenario, it became quite easy to analyze the output of the problem statement.

For the First In First Out (FIFO) rule, from the queue module (basic process template), “Type” was selected as FIFO for priority. The output performance measuring parameters that were obtained after running the model for FIFO is given in Fig. 6.

Similarly, the output was generated for the remaining dispatching rules by adjusting the queue types. In order to compare the outputs among the priority dispatching rules on performance, a scenario analysis was carried out to choose the best dispatching rule satisfying the performance measuring parameters. The scenario analysis table for the dispatching rules are given in Table 3.

<table>
<thead>
<tr>
<th>SL.</th>
<th>Name</th>
<th>Makespan (minutes)</th>
<th>Overall utilization</th>
<th>System average queue waiting time (minutes)</th>
<th>System average queue length</th>
<th>System avg WIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>FIFO</td>
<td>45</td>
<td>2.4000</td>
<td>5.6944</td>
<td>0.6667</td>
<td>3.0667</td>
</tr>
<tr>
<td>02</td>
<td>LIFO</td>
<td>46</td>
<td>2.3478</td>
<td>5.9638</td>
<td>0.6957</td>
<td>3.0435</td>
</tr>
<tr>
<td>03</td>
<td>SPT</td>
<td>47</td>
<td>2.2979</td>
<td>7.4326</td>
<td>0.7872</td>
<td>3.0851</td>
</tr>
<tr>
<td>04</td>
<td>LPT</td>
<td>49</td>
<td>2.2041</td>
<td>8.0714</td>
<td>0.9388</td>
<td>3.1429</td>
</tr>
<tr>
<td>05</td>
<td>EDD</td>
<td>52</td>
<td>2.0769</td>
<td>8.2452</td>
<td>0.7692</td>
<td>2.8462</td>
</tr>
</tbody>
</table>

If the dispatching rules are ranked with 5-point system (where 1 represents the worst performance and 5 represents the best performance) according to each performance measuring parameters, it will be easier to declare the best dispatching rule for the job shop manufacturing unit. For makespan and system average queue waiting time, the less value result determines that the task takes less time to complete the jobs. In ranking of makespan and system average queue waiting time, the least value is given 5 points and the highest value is given 1 point. For system average queue length and WIP, the less value result determines that the number of jobs waiting less time in the machine queue or the system. In ranking of system average queue length and WIP, the least value is given 5 points and the highest value is given 1 point. For overall utilization, the less value result determines that the number of job scheduling is less in a resource set. In the ranking of overall utilization, the highest value is given 5 points and lowest value is given 1 point. The total scoreboard is shown in Table 4.
According to the score of dispatching rules, FIFO scored highest among other dispatching rules. So, it can be stated that FIFO dispatching rule performed better than LIFO, SPT, LPT, and EDD for the workshop for job shop scheduling problems in real life.

Before using any scheduling methods, the task was completed in 108 minutes. If they use FIFO dispatching rule, the task can be completed in 45 minutes. Though the development of the Arena model of JSSP, time savings can be increased by 58.33%.

\[
\text{Saved time by using FIFO} = \frac{(108-45)}{108} \times 100\% = 58.33\%
\]

6. Conclusion

To get the best approach of the scheduling problem in a job shop production, at first, a conceptual model was developed and then an Arena model has developed based on the conceptual model for the cause that it can be used for representing all the scenarios of such environment just by changing the variables. A replica of an existing system was created on the Arena model and some common dispatching rules were checked in the model. Finally, after analyzing the results of the performance measures, it can be stated that FIFO provides the best result in this case than all the priority rules.

The workshop from where the data were collected, does not follow any scheduling method in their production. There are no scheduling technique or software application in this case workshop. They only maintain the sequence of the products while machining, but they execute them one after another. For this reason, the workshop faces lots of problems. The total makespan of these four jobs were 108 minutes, but after calculation, we found that all scheduling rules give much better result than this. The best result can be obtained by FIFO in this case. By following, the FIFO scheduling rule, the makespan can be reduced to 45 minutes, which means 58.33% time can be saved in this job shop scheduling problem.

7. References


