Scheduling to Minimize Total Completion Time of Jobs in a Printing Firm.

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ABSTRACT

The problem of scheduling a set of jobs on a single machine in order to minimize the total completion time of all jobs with release dates was considered. The case of a printing firm that is involved in the production of scientific publications such as monographs and workshop proceedings was studied. Real life data were collected from the firm using a standard work order format.

Existing solution methods (AEO and BESTA) for this problem were selected from the literature and then applied to the data collected alongside the company's policy of first-come first-serve (FC). Experimental results on the performance of the solution methods were presented. Based on substantial reduction in production cost of 41.12% the AEO solution method was recommended to the firm as an alternative to the firm's current policy. The recommended solution method (AEO) is also easy to implement.

(Keywords: scheduling, signal machine, total completion time, performance measure, heuristic)

INTRODUCTION

Scheduling deals with the problem of allocating resources (machines) over time to perform a number of tasks (jobs) with the aim of minimizing cost or maximizing profit. The problem is essentially a decision-making problem and it occurs frequently in almost all facets of life. Examples include: jobs waiting for processing in a manufacturing plant; programs to be run on a computer system; bank customers waiting for services in front of tellers' windows; airplanes awaiting clearances to land or take off at an airport; patients waiting for treatment in a hospital; cars waiting to be repaired in a garage, etc.

Some problems may require only one machine (single machine problems) while others require two or more machines (multi-machine problems). The order in which tasks (jobs) are performed on the machine(s) is of interest to the decision maker. Usually, the order adopted affects the value of an objective (performance) measure. The problem is to determine the optimum ordering (sequence) which best meet the set objectives. Scheduling objectives are some measure of goodness of solutions to scheduling problems (Uthaisombut, 1999). These objectives often vary from firm to firm. Some of the objectives of scheduling problems include: minimization of total completion time, number of tardy jobs, maximum completion time, maximum lateness, etc.

In this work, the objective measure of interest is the total completion time. A key feature of the total completion time is that it gives an indication of inventory characteristics (Oyetunji and Oluleye, 2007). A printing company was used as a case study. The company has many customers bringing work orders (jobs) which are processed on first-come first-serve basis. Real life data was collected from the company and its production practice (first-come first-serve policy, also called FC) was compared with some solution methods (BESTA and AEO algorithms) with a view to recommend to the company a better sequence of processing the work orders. Performance evaluation of the solution methods (FC, AEO, and BESTA) were based on both effectiveness (a measure of the closeness of the value of the total completion time to the optimal) and efficiency (a measure of the speed of the solution method).

LITERATURE REVIEW

The problem of minimizing the total completion time of jobs with release dates on a single machine is strongly NP-hard (Chakrabarti et al., 1996; Karger, Stein and Wein, 1997; Phillips, Stein, and Wein, 1998; Chekuri et al., 2001; and Goemans et al. 2002). Therefore, researchers have focused on the development of approximation algorithms for this problem. Some of the previous works in the area have produced a number of constant-factor approximation algorithms (Chakrabarti et al., 1996; Hoogeveen and Vestjens, 1996; Phillips, Stein, and Wein, 1998; Torng and Uthaisombut, 1999; Uthaisombut, 2000; and Chekuri et al. 2001). A constant-factor approximation algorithm is an algorithm that produces solutions that are within a constant factor of the optimal values of the criteria.

A constant-factor approximation algorithm (called an α-scheduling Algorithm) for this problem was given by Philips et al. (1998). The work of Philips et al. (1998) was improved upon by Chekuri et al. (2001) to yield total completion time upper bound that is 1.58 times the optimal value of total completion time.

An algorithm called Best Alpha (BESTA) achieves this. BESTA algorithm has been studied by other researchers with the conclusion that the upper bound of 1.58 is tight (Torng and Uthaisombut, 1999; Uthaisombut (2000).

Oyetunji and Oluleye (2007) proposed an algorithm called AEO for this problem. They evaluated the AEO and BESTA algorithms on a set of randomly generated problems covering 3 to 500 jobs and found out that the AEO algorithm performed better than the BESTA algorithm when the number of jobs exceeds 6.

CASE STUDY: PRINTING COMPANY

The Printing Company used as the case study is a limited liability company situated in the South Western part of Nigeria. The company is involved in the production of:

a. Research monographs
b. Workshop proceedings

It is equipped with a sophisticated printing machine and customers bring jobs (monographs or proceedings) to the company by completing a standard work order containing information such as: name of customer (originator), description of the job, the date the work order was brought, the date the work order is required, the date the work order is completed (this is to be completed by the company), estimated cost (to be completed by the company), estimated processing time (days) among others.

METHOD OF DATA COLLECTION

The basic data required are the release date, processing time and due dates of each job. Real life data was collected using the company's standard work orders as follows:

Release Date

The release time is the earliest time at which the processing of each job can begin and it is sometimes called the ready time or release date. It is the time each job arrives at the shop. Therefore, the date the work order was brought was used as the release date of the job. We assumed that scheduling starts from the 1st day of the month, so if a work order was brought on 12th of January, the release date is 12. Therefore, release dates have values ranging between 1 and 31 inclusive depending on the month of the year.

Due Date

The due date is the latest time by which each job is due to be delivered to the customer. The date the work order is required was used to compute the due date.

For example, if the work order is required on the 20th of February, then the due date will be 31 days in January plus 20 days in February, which gives 51 days.

Processing Time

The processing time is the amount of time unit required by each job to be processed on the machine. The estimated processing time of each work order was used as the processing time of the work order. The estimate is normally carried out by the production manager.

Problem Sizes

The size of a problem is determined by the number of jobs (designated as n) and the number of machines (designated as m). For a single machine case, m = 1. Because of the structure of solution methods, some solution methods perform better under some particular problem loading (sizes) than others. In evaluating the performance of solution methods, they are tested on a wide range of problem sizes.

In this study, nine (9) different problem sizes were utilized as follows. Work orders for each month were pooled together, so that a month represents an instance of a problem. Fifty (50) work orders were obtained in each month. Problem sizes were determined by using the first 10, 15, 20, 25, etc. work orders for each month. About 10 instances (months) of real life data for 9 different problem sizes (10, 15, 20, 25, 30, 35, 40, 45, and 50) were collected.

Production Practice

The firm currently treats customer's work orders on a first-come first-serve basis. This means that the work orders are treated (processed) in the ascending order of the date they were brought to the company (release date). This rule was implemented and is called FC so as to determine the variance between the firm's practice and the other solution methods that are being applied.

SOLUTION METHODS

A number of approximation algorithms have been proposed for the single machine problem of minimizing the total completion time of jobs with release dates. Based on performance, two existing solution methods were selected from the literature. They are described below:

The BEST Alpha (BESTA) Algorithm

The Best Alpha (BESTA) algorithm is a polynomial time approximation algorithm developed for the single machine scheduling problem of minimizing the total completion time of jobs with release dates by Chekuri et al. (2001). A polynomial time algorithm is one which constructs solution in polynomial time. The BESTA algorithm first constructs a preemptive schedule using the shortest remaining processing time (SRPT) rule, then constructs n non-preemptive schedules by varying the value of alpha (α = [0,1]) proceeding to select the best out of the n non-preemptive schedules. The steps for the Best Alpha algorithm (BESTA) are now outlined:

Step 1: Construct a pre- emptive schedule P using the shortest remaining processing time (SRPT) rule. SRPT, at any time, runs an available job that has the least processing time left. Let α=1/n.

Step 2: Compute the time at which an α portion of each job has been completed in preemptive schedule P, call this $C_i^P(\alpha)$; where α = [0,1], n different values of α are considered.

Step 3: Form a list L of jobs, ordered by their respective completion times $C_i^P(\alpha)$.

Step 4: Construct a non-preemptive schedule by list scheduling using L with the constraint that no job J_i starts before its release date r_i.

Step 5: $\alpha = \alpha + 1/n$

Step 6: If $\alpha \leq 1$ then go to Step 2, otherwise go to Step 7.

Step 7: Select the best of the n, α - schedules as the solution.

Step 8: Stop.

The AEO Algorithm

The AEO algorithm was proposed by Oyetunji and Oluleye (2007) for the single machine scheduling problems of minimizing the total completion time of jobs with release dates. The basic idea consists of choosing a job with the least processing time among the set of jobs that have arrived and are available for processing at time t until all the jobs have been scheduled. The AEO algorithm selects the job to process each time the machine becomes idle or a new job arrives. The AEO steps are outlined below.

Step 0: Initialize

Job_SetA={J_1, J_2,…,J_n}; This is the set of given jobs

Job_SetB={.} This is the set of scheduled jobs

Job_SetC={J_1, J_2,…,J_n} This is the set of unscheduled jobs

Job_SetD={.} This is the set of available jobs at time t

t = $\min_{J_i \in Job\_SetA} r_i$ (i.e. the minimum ready time of all jobs)

Step 1: At time t
Update Job_SetD with jobs for which r_i<=t.
If r_i <= t then Job_SetD = {J_i}

Step 2: Choose the job with the smallest processing time among the jobs that have arrived at time t from Job_SetD

Step 3: Add the job chosen in step 2 to Job_SetB and remove the same job from Job_SetC. Compute start time S_i = t and completion time $C_i = S_i + p_i$

Step 4: Compute new time as: t = max (C_i, $\min_{J_i \in Job\_SetC} r_i$) ; max of the completion time or the minimum ready time of the remaining unscheduled jobs.

Step 5: If Job_SetC is not empty go back to step 1 otherwise proceed to step 6.

Step 6: Job_SetB is the schedule required.

Step 7: Stop.

DATA ANALYSIS

A program was written in Microsoft Visual Basic® 6.0 to apply all the solution methods (AEO, BESTA, and FC) to the real life data collected from the printing firm. The program computes both the value of the total completion time (a measure of effectiveness) and the execution time (a measure of efficiency) required to solve an instance of a problem by each solution method for each problem. The output data was then exported to Statistical Analysis System® (SAS® version 9.1) for detailed analysis. SAS® is a very versatile statistical package and was employed to enable credible conclusions to be drawn from the results. The hardware used for the experiment is a 2.4 GHz Pentium® IV with 512MB of main memory.

The general linear model (GLM) procedure in SAS® was used to compute both the mean value of the total completion time and the mean value of execution time required for each problem size and by solution methods. The test of means was also carried out using the GLM procedure so as to determine whether or not the differences observed in the mean value of the total completion time and mean value of execution time required by various solution methods are statistically significant. Also, the relative effectiveness of the solution methods was computed from the ratio of the value of total completion time. A similar ratio was computed for the relative efficiency.

RESULTS

The mean value of the total completion time (days) obtained by the solution methods (BESTA, AEO, and FC) under different sizes of work orders considered are shown in Table 1. Based on the minimum mean value of the total completion time criterion (a measure of the effectiveness of the solution methods), the AEO and BESTA solution methods outperformed the FC method (the company's policy) for all the sizes of work orders considered (see Table 1). Also, the AEO method performed marginally better than the BESTA method for most sizes of work orders considered.

The possible gains or savings to the company if either the AEO or the BESTA methods is adopted instead of the first-come first-serve (FC) policy were obtained (see Table 2). In order to compute the gains (days) per work order, the results were divided by the number of work orders (see Table 3). When, the first ten work orders received in the month were considered, applying either the AEO or BESTA, methods resulted in reductions of the average completion time of 3.96 or 4.10 days respectively over the use of first-come first-serve policy (Table 3).

Table 1: Means of Total Completion Time (days).

Problem Size	Solution methods		
	BESTA	**AEO**	**FC**
10x1	95.59	97.05	136.61
15x1	206.71	204.88	305.18
20x1	348.89	345.22	540.19
25x1	518.23	518.80	835.83
30x1	717.87	715.90	1174.98
35x1	975.35	973.10	1615.15
40x1	1273.03	1270.90	2134.51
45x1	1613.89	1610.65	2720.72
50x1	1992.40	1989.56	3379.19

Sample size = 10

Table 2: Gains with Respect to Total Completion Time (days).

Problem Size	Gains	
	FC - BESTA	**FC - AEO**
10x1	41.02	39.56
15x1	98.47	100.30
20x1	191.30	194.97
25x1	317.60	317.03
30x1	457.11	459.08
35x1	639.80	642.05
40x1	861.48	863.61
45x1	1106.83	1110.07
50x1	1386.79	1389.63

Sample size = 10

Table 3: Average Gains with Respect to Total Completion Time.

Problem Size	Average gains (days/work order) (FC – BESTA)/N	(FC - AEO)/N
10x1	4.10	3.96
15x1	6.56	6.69
20x1	9.57	9.75
25x1	12.70	12.68
30x1	15.24	15.30
35x1	18.28	18.34
40x1	21.54	21.59
45x1	24.60	24.67
50x1	27.74	27.79

Sample size = 10
Where, N = number of work orders or jobs

The results shown in Table 1 were subjected to statistical tests to determine whether the differences observed in the mean value of the total completion time obtained by the various solution methods were significant (see Table 4). The differences in the mean value of total completion time obtained for the AEO and BESTA methods are not significant at the 5% level. However, the mean value of total completion time obtained by the AEO and BESTA methods is significantly different from (better than) that of the FC method (Table 4). This implies that both the AEO and BESTA methods are much more effective than the FC method. Also, the AEO method is marginally better (more effective) than the BESTA method (Table 1).

Also, when the BESTA and the FC methods were compared with the AEO method by computing the overall mean value of the approximation ratios: BESTA/AEO and FC/AEO, it was discovered that the AEO method was better than the BESTA and FC methods by 0.2% and 60.5%, respectively (Table 5).

Table 4: Test of Means of Total Completion Time.

Solution methods	Solution methods BESTA	AEO	FC
BESTA	-	X	*
AEO	X	-	*
FC	*	*	-

Note * indicates significant result at 5% level; Sample size = 10
X indicates non significant result at 5% level
- indicates not necessary

Table 5: Overall Means of Approximation Ratio with Respect to Total Completion Time.

Solution methods	Overall means
BESTA/AEO	1.0015
FC/AEO	1.6046

Sample size = 500

The mean value of execution time (seconds) obtained by the solution methods for various sizes of the work orders considered are shown in Table 6. It is clear that the AEO and FC methods are faster than the BESTA method. For example, the AEO and FC methods took less than 1 second to obtain solution for a 50 work orders problem, whereas, the BESTA method took more than 1 second to obtain solution for a 10 work orders problem (Table 6). This means that the AEO and FC methods are more efficient (faster) than the BESTA method.

Similarly, the mean value of the execution times obtained by the various solution methods were subjected to a statistical test to determine whether or not the differences observed in the mean value of the execution time are significant. The mean value of the execution time obtained by the FC method is significantly different from (faster than) that of the AEO and BESTA methods. Also, the mean value of the execution time by the AEO method is significantly different from (faster than) that of the BESTA method (Table 7). This implies that the FC method is the most efficient (fastest) and this is closely followed by the AEO method. The BESTA method is not efficient given the results.

In order to establish the relative speed of the FC method over the AEO and BESTA methods, the approximation ratios: BESTA/FC and AEO/FC were computed with respect to execution time. It was found out that the FC method was faster than the AEO and BESTA methods by a factor of 28.0722 and 1354.0007, respectively (Table 8).

On the average, the firm incurs the followings costs per day: 1. Capital costs of Naira 18,000.00 ($138.46), 2. Operational costs of Naira 15,000.00 ($115.38), 3. Labor costs of Naira 21,000.00 ($161.54), and 4. Other costs of Naira 9,000.00 ($69.23). The total cost per day is $484.61. Therefore, the cost that will be incurred by the firm when the various solution methods are adopted are shown in Table 9. These were obtained by dividing the results shown in Table 1 by the number of work orders and then multiplying by the total cost per day. Table 10 shows the percentage reduction in cost when either the BESTA or AEO methods are used instead of the firm's FC policy. For example, the BESTA and AEO methods resulted in reduction of production cost of 41.04% and 41.12% respectively for a fifty work order problem (Table 10).

Table 6: Means of Execution Time (seconds)

	Solution Methods		
Work orders	**AEO**	**BESTA**	**FC**
10	0.0105	1.0004	0.0014
15	0.0172	1.6684	0.0016
20	0.0297	2.2543	0.0016
25	0.0453	2.9468	0.0016
30	0.0656	3.5824	0.0031
35	0.0954	4.0906	0.0031
40	0.125	4.7812	0.0031
45	0.1613	5.6304	0.0031
50	0.2031	6.3180	0.0047

Sample size = 10

Table 7: Test of Means of Execution Time.

	Solution methods		
Solution methods	**BESTA**	**AEO**	**FC**
BESTA	-	*	*
AEO	*	-	*
FC	*	*	-

Note * indicate significant result at 5% level; Sample size = 10
X indicate non significant result at 5% level
- indicate not necessary

Table 8: Overall Means of Approximation Ratio with Respect to Execution Time.

Solution methods	**Overall means**
BESTA/FC	1354.0007
AEO/FC	28.0722

Sample size = 500

Table 9: Average Daily Cost (USD) by Solution Methods.

	Solution methods		
Work Order	**BESTA**	**AEO**	**FC**
10	4632.39	4703.14	6620.26
15	6678.25	6619.13	9859.55
20	8453.78	8364.85	13089.07
25	10045.58	10056.63	16202.06
30	11596.23	11564.41	18980.24
35	13504.7	13473.54	22363.37
40	15423.08	15397.27	25860.12
45	17380.16	17345.27	29299.74
50	19310.74	19283.21	32751.79

Sample size = 10

Table 10: Percentage Reduction (%) in Cost by Solution Methods.

Work Order	**BESTA**	**AEO**
10	30.03	28.96
15	32.27	32.87
20	35.41	36.09
25	38.00	37.93
30	38.90	39.07
35	39.61	39.75
40	40.36	40.46
45	40.68	40.80
50	41.04	41.12

Sample size = 10

CONCLUSION

It has been shown that the current scheduling policy (first-come first-serve) being adopted by the company is fast (efficient) but obtains poor total completion time values (poor effectiveness). Two algorithms (AEO and BESTA) selected from the literature were evaluated alongside the company's policy (FC).

The results of the analysis carried out show that the AEO method is better (in terms of effectiveness) than the current production practice of the company (first-come first-serve). From the analysis of the total costs incurred by the firm per day, an average reduction in the production cost of **41.04%** and **41.12%** was obtained when the BESTA and AEO methods respectively were adopted over the FC method when all the fifty work orders were considered. In view of this substantial gain, the AEO algorithm is recommended to the company for operational scheduling of printing jobs.

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