Job-Shop Sequencing Real Life Problem With Setup Time

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Abstract

In this paper, we analyzed the sequencing situations on two machines where the machine setup time is not independent of processing order.

A real case study of Hadhramout Industrial Company Complex, Mukalla, Yemen is taken as a model. Data is collected and analyzed using *MS-Excel* by different methods. The problem formulation has been presented. Multiple solutions were obtained by applying sequencing methods. The comparison of different solutions is done to choose the optimal solution. The time is reduced by 23% to perform the group of jobs and the setup time is reduced 30.5% as well as the mean flow time is reduced by 30.5%.

Keywords: Setup Time, Sequencing, Processing Time, Idle Time, Scheduling, Ordering.

مشكلة تتابع الأعمال في ورش الانتاج في حالة اعتماد أوقات تهيئة المكائن

ألخلاصه

تناول هذا البحث تحليل مشكلة تتابع مجموعة اوامر العمل على المكائن في حالة افتراض ان اوقات اعداد وتهيئة المكائن للانتاج مستقله ومتباينه وغير معتمده على ترتيب اوامر العمل. في بداية البحث تمت صياغة المشكله بتصميم نموذج رياضي مقترح وتم حل النموذج وتطبيقه على حاله دراسية واقعية في المجمع الصناعي لحضرموت في المكلا , حيث جمعت المعلومات وتم تحليلها باستخدام مايكروسوفت-الاكسل. وبالتطبيق تم التوصل الى مجموعة بدائل,تمت عملية المقارنه بينها لاختيار البديل الامثل . ومن بين النتائج المميزه للبحث في الجانب التطبيقي , تخفيض نسبة 23% من زمن انجاز مجموعة الاعمال مقارنة بالحالة الاعتياديه وتقليص اوقات الاعداد والتهيئه وتضبيط المكائن بنسبة 30.5% اضافة الى تقليل متوسط زمن التدفق بنسبة 30.5%. اخيرا قدم البحث مجموعة من الاستنتاجات العمليه مع بعض التوصيات للبحوث القادمه في مجال جدولة وتحميل المكائن.

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1. Introduction

Flow shop scheduling is one of the most important problems in the area of production management. It can be briefly described as follows: There are a set of *m* machines (processors) and a set of *n* jobs. Each job comprises a set of *m* operations which must be done on different machines. All jobs have the same processing operation order when passing through the machines. There are no precedence constraints among operations of different jobs. Operations cannot be interrupted and each machine can process only one operation at a time. The problem is to find the job sequences on the machines which minimize the make span, i.e. the maximum of the completion times of all operations. As the objective function, mean flow time, completion time variance and total tardiness can also be used. According to Weng and Haiying (2006) , the flow shop scheduling problem is usually solved by approximation or heuristic methods. These methods ranged from Gantt charts and the assighment methods of scheduling to a series of priority rules, the critical – ratio rule, Johnson's rule for sequencing, and finite capacity scheduling. (Heizer and Render(2006)).

Scheduling has been defined as 'the art of assigning resources to tasks in order to insure the termination of these tasks in a reasonable amount of time'. According to Voss et. al. (2002), the general problem is to find a sequence, in which the jobs pass between the resources, which is a feasible schedule, and optimal with respect to some performance criterion. Blazewicz (2005) introduced a functional classification scheme for scheduling problems. This scheme categorizes problems using the following dimensions:

1. Requirement generation,
2. Processing complexity,
3. Scheduling criteria,
4. Parameter variability,
5. Scheduling environment.

In the literature, there are many papers published in which the sequencing issue is tackled and investigated. Aggarwal (1975) presented a scheduling algorithm to solve

flowshop problems with a common job sequence on all machines. This algorithm used makespan as its criterion and offered up to 1% average improvement in reducing the makespan of nearly 50% of the problem sets over the results of the existing algorithms.

Caffrey and Hitchings (1995) considered scheduling of five jobs through a flow shop with five machines. They obtained the distribution of make spans and the distribution of the optimal make spans by complete enumeration of all the schedules. Torres and Centeno (2008) considered a permutation flow shop problem with secondary resources with the objective of minimizing the number of tardy jobs. He presented a lower bound for the permutation flowshop problem and evaluates its performance against the optimal solution for small, medium, and large instances. Weng and Haiying (2006) presented a priority rule for dynamic job shop scheduling that minimizes mean job tardiness.

Chan et. al. (2005) developed an assignment and scheduling model to study the impact of machining flexibility on production issues such as job lateness and machine utilization and suggested an improvement of overall production performance if the equilibrium state can be quantified between scheduling performance and capital investment. Also Chan et. al. (2006) solved a resource-constrained operations–machines assignment problem and flexible job-shop scheduling problem iteratively.

Konstantin et. al. (2005) focused on a dynamic generalization of the assignment problem where each task consists of a number of units to be performed by an agent or by a limited number of agents at a time.

Also, Gupta et. al. (2004) considered a variant classical problem of minimizing makespan in a two-machine flow shop. In this variant, each job has three operations, where the first operation must be performed on the first machine, the second operation can be performed on either machine but cannot be preempted, and the third operation must be performed on the second machine. They showed that a schedule in which the

operations are sequenced arbitrarily, but without inserted machine idle time, has a worst-case performance ratio.

Recently, Agarwal (2006) proposed a meta-heuristic approaches for the two-machine flow-shop problem with weighted late work criterion and common due date. Also, Petrovic and Song (2003) introduced a new approach to two-machine flow shop problem with uncertain processing time. In their paper, flow shop problem with uncertain processing time was represented with fuzzy number. Especially, the scheme used in McCahon and Lee's algorithm for ranking fuzzy processing times was modified to calculate better minimum makespan.

In this paper, we analyzed sequencing situations under two machines where the machine setup time is dependent taken into account for the real industrial company.

1.1 Priority Rules and Assumptions

In the literature, a number of priority rules are simple heuristics used to select the order in which jobs will be processed. Such rules are given in the Table 1.

The rules generally rest on the assumptions that job setup time and cost are independent of processing sequence. By using these rules, job processing time and due dates are important pieces of information. Job time usually includes setup and processing times. Jobs that require similar setups can lead to reduced setup time if sequencing rules are taken into account. Also, it should be noted that the priority rules can be classified as either local or global.

Local rules are taken into account for information pertaining only to a single machine while global rules are taken into account for information pertaining to more than one machine. Moreover, a number of following assumptions are applied when we use priority rules:

1. The set of jobs is known, no jobs arrive after processing begins, and no jobs are cancelled.
2. Setup time is independent of processing sequence.
3. Setup time is deterministic.
4. Processing times are deterministic.

The effectiveness of any given sequence is frequently judged in terms of one or more performance measures. The most frequently used performance measures are, job flow time, job lateness, makespan and average number of jobs.

Johnson described a heuristic method that can be used for the case where a set of jobs is to be processed through two machines. In this technique, the managers can use to minimize makespan for a group of jobs to be processed on two machines or at two successive work centers (sometimes referred to as a two-machine flow shop). For the technique to work, several conditions must be satisfied:

1. Job time including setup and processing must be known and constant for each job at each work centre.
2. Job times must be independent of the job sequence.
3. All jobs must follow the same two-step work sequence.
4. Job priorities cannot be used.

5. All units in a job must be completed at the first work center before the job moves on to the second work center.

1.2 The Theory of Changeovers

The preceding discussion assumed that all the rules are used where the setup time is independent of processing order, but in many instances that assumption is not true. Consequently, a manager may want to schedule jobs at a machine taking into account those dependencies. The goal is to minimize total setup time or changeovers.

Changeovers are the steps that need to be taken to prepare equipment and worker to do a new job. The term setup is usually applied to the start up of a new job, which means the cleanup from the old one. For process analysis, it is best to separate these two steps and deal with the setup and put away (cleanup) as two activities.

The critical importance to job shop processes is the changeover cost and time. These are often treated as being synonymous so that mention of cost implies and vice-versa. Thus, the generic term setup is often used to include time and cost everything that has to be done to change the process from one product to another.

Setup costs are often proportional to setup times. However, the relationship breaks down when a lot of technology is devoted to allow very rapid setups. Then there is a cost of not using this technology for the purposes for which it was intended, namely, short runs of many designs that fit within the family of parts (technology group) that can be made on this equipment. Further, when the setup can take place off-line, it can take longer and still cost much less than when it must interrupt the production process.

Machines have to undergo cleanup prior to job processing and then reset. Operators have to shift jobs, often moving from one location to another. The learning curve comes into play every time operators bring a new order online which is also a part of the changeover process.

Finally, we should organize that setting up times and differ according to requirement of each job and whether a system is designed for high volume, or low volume. Some jobs may need to change a specific tools and equipment on a particular machine while other jobs may need to replace some devices to operate. Consequently, the problem of sequencing will be more complicated by the variable number of each job in terms of processing time and coordination of setup times.

2. A Model

As shown in previous section of this paper, sequencing can be difficult for a number of reasons. One is that in reality, an operation must deal with variability in setup time, processing times, changes in the set of jobs.

For a description of a heuristic that can be used for the case where a set of jobs is to be processed through one machine given the setup time. Consider the following table which shows workstation machine setup times based on job processing order:

			Resulting following Job setup time (min) is		
		Setup time (minutes)	*J1*	*J2*	*J3*
If the processing job is	*J1*	6	-	12	4
	J2	4	2	-	8
	J3	4	10	6	-

Note if job J1 is followed by J2, the setup time for J2 will be 12 minutes. Furthermore, if job J1 is completed first, followed by job J2, job J3 will then follow job J2 and have a setup time of 8 minutes. Then if job J1 is done first, its setup time will be 6 minutes.

The simplest way to determine which sequence will result in the lowest total setup time is to list each possible sequence and determine its total setup time. In general, the number of different alternatives is equal to n!. Here, n is equal to 3, so there are six alternatives and their total setup time is as follows:

Sequencing	*Total Setup time (minutes)*
J1-J2-J3	26
J1-J3-J2	16
J2-J1-J3	10
J2-J3-J1	22
J3-J1-J2	26
J3-J2-J1	12

This procedure is relatively simple to do manually when the number of jobs is two or three. However, as the number of jobs increases, the list of alternatives quickly becomes larger, since if the number of machines is more than one. Thus, sequencing will be difficult for this reason.

In this study, we will analyze sequencing situations under two machines where the setup time would be considered as a factor.

3. Problem Formulation

To form the general model subject to the setup time, the procedure for two machines is considered for setup time as a main factor influencing the sequence of a set of jobs. The following notations are used to design the model:

PT_{ij} : Processing Time of Job i on Machine j

N : Number of jobs to be completed

M : Number of Machines in the workshop

TI_{ij} : Starting Time for Job i on Machine j (Time in)

ST_{ij} : Setup time for Machine j where Job i is performed on it

TST_{ij} : Total Setup time for Machine j where all jobs are performed on it (i=1,2,...,n)

$TTST_{ij}$: Total Setup time for all machines where all jobs are performed on them (i=1,2,...,n and j=1,2,...,m)

$$TST_{ij} = \sum_{i=1}^{n} ST_{ij} \qquad j=1,2,...,m \qquad .....(1)$$

$$TTST_{ij} = \sum_{j=1}^{m}\sum_{i=1}^{n} ST_{ij} \qquad .....(2)$$

Z: Summation of total setting up times for all the machines for performing n jobs.

The objective function Z will give the total setting up time for all machines to complete all the jobs.

Now we can form the problem of sequencing if we consider two machines which will be fit with our case study taken from an industry.

Thus, the cells in the setup time matrix will differ accordingly based on job processing order, which job follows and which job immediately predecessor.

Our objective is to find the minimum total setup time on all machines for all the jobs, which can be represented as follows:

$$TTST_{ij} = \sum_{j=1}^{m}\sum_{i=1}^{n} ST_{ij} \quad .(3)$$

4. Implementation

To implement the formula and to achieve the above objective, a real case study has been taken from industry. A group of ten jobs are to be processed through two machines flow shop. The first operation involves *Vertical Cutting* and the second operation involves *Circular Cutting*. In the existing system, the set of jobs are processed in the same order in which they reached the department. To implement the model, the jobs are labeled in serial number as they arrived to the flow shop. The respective processing time for each job is given in the Table 3. Jobs are listed in order of arrival and the processing time is in hours.

The Table 4 and Table 5 contain order dependent setup times for all jobs on Vertical Cutting Machine and Circular Cutting Machine respectively. The data shows the setup time for each machine in the flow shop. These times are in minutes. Note that the time for undergoing cleanup prior job processing and then be reset is included.

5- Data Analysis

5.1. Existing System

In the existing system, the production manager orders the jobs arbitrary and mainly using First Come First Served (FCFS) rule, i.e. the jobs are going to machine for processing in the order in which they are arriving. By scheduling the jobs in the order of Machine 1 (Vertical Cutting) and Machine 2 (Circular Cutting), we calculated the total setup cost for all jobs. The complete summary of the calculation for the existing system is shown in the Table 6.

In the Table 6, the following notations are used:

Notation	*Meaning*
M1 and M2	Vertical Cutting Machine and Circular Cutting Machine
T(M1) and T(M2)	Time of processing for a job for Machine 1 and Machine 2 respectively
Ti	Time in of a job on a machine
To	Time out of a job on a machine
ST_1	Setup time required for Machine 1 to process a job
ST_2	Setup time required for Machine 2 to process a job
TST	Total Setup time required for two machines to process a job

It is clear from the Table 6 that all the ten jobs must be processed by Machine 1 and Machine 2 in 72 and 68 hours respectively but due to idle of the machines, all the jobs will be finished in 72 and 94 hours.

Total setup time for Machine 1 and Machine 2 for all jobs will be 118 minutes and 167 minutes respectively. So the total setup time for both machines required to process all the jobs in the existing sequence will be 285 minutes. In this sequence, the mean flow time is 65.3 (653/10) hours.

5.2. Searching The Optimum Sequence

By applying the efficient algorithm suggested by Johnson (1954) for solving two machine problems, multiple optimum sequences are generated. Each sequence is like an array of size 10 cells starting from left to right. These four sequences obtained are labeled as S1, S2, S3, and S4. The order of the jobs in each sequence is shown inside the chart.

These four sequences are generated from approximately 3628800 permutation sequences. Here, we have to note that in theory, a solution by enumeration is always possible, but in practice, the computation of effectiveness for a given sequence can be quite involved and the number of cases for prohibitive even for moderate number of machines . So, by using Johnson's algorithm, only sequences which are optimal in terms of the total time (completion time) to process all the group of jobs on both machines is minimum among all possible sequences generated.

So far we computed the relative result for the existing order. Now we extend the analysis and carry on to find the optimal sequence in terms of minimum total setup time (Min Z). So we consider each optimum sequence which has been obtained. We calculated the compilation time to perform all the jobs and computed the mean flow time as well as setup time using *MS-Excel*.

The calculation is based on Table 4 and Table 5. The results are presented in the following tables i.e. Table 8, Table 9, Table 10 and Table 11 for the sequences S1, S2, S3 and S4 respectively.

It is obvious from each solution that the total time to complete all the jobs is 73 hours for all the solutions. Hence each solution is an optimum solution in case of minimum completion time. But if production manager considers the setup time, it varies as well as the mean flow time as shown in the tables.

Each sequence has different order of jobs which can be represented in a Gantt chart. The Gantt chart in Figure 1 is for sequence S3. This Gantt chart is prepared by using POM software which is very useful to demonstrate how the jobs are carried out. The time scale on each machine is shown as starting and ending time. Inside the chart, jobs are written in order for sequence S3. Each job has to wait for Machine 2 until it is free. For example, Job 8 (J8) is finished from Machine 1 after 20 hours and it will not go directly to Machine 2 until it is free. So, Machine 2 will be free after 31 hours and J8 has to wait until 31 hours for Machine 2. Opposite to this situation, sometimes the machine has to wait for jobs. As happened for Machine 2, it will finish from Job 7 (J7) at 65 hours while it will not start to perform Job 1 (J1) until J1 is finished from Machine 1. That means, Machine 2 has to wait 3 hours. This time is known as idle time and it is marked as shadow.

6. Comparison Of The Study

The result for existing and proposed system is summarized in the Table 12.
It can be seen from the Table 12 that

- the time taken by Machine 1 (Vertical Cutting) is 72 for all the sequences as well as by existing sequence, while time taken by Machine 2 (Circular Cutting) is 94 for existing which is reduced to 23% for each proposed sequence,

- the setup time is drastically reduced by approximately 44% on Machine 1 and 21% on Machine 2 for the proposed solution (S3) as compared to the existing one.

Moreover, it is obvious that the third sequence generates the optimal solution according to the different factors. It gives the minimum time to finish all the jobs and contains lowest setup time for all the jobs on both machines (Min Z). The significant reduction occurs in mean flow time by almost 46.5%. Although, the study generated four multi-solutions by MS-Excel but the third sequence (S3) gives the best optimal solution in terms of setup time and completion time.

7. Conclusions

In this paper, a model for calculating the setup time is suggested. A case study of real life is analyzed by using MS-Excel by different methods. A significant result is generated which gave four solutions equally in completion and mean flow time but they are differ in terms of setup time. A unique solution (sequence S3) comes with the amazing result with minimum setup time among all four sequences.

The major findings of this study are generating different solutions with equally lowest compilation time to finish all the group of jobs. The comparison of different solution is done to choose the optimized solution. Particularly, for the sequence S3, the time is reduced by 23% and the setup time is reduced by 30.5% (87/285) for both machines as well as the mean flow time is reduced by 30.5%.

8. Recommendations For Further Work

Based on the empirical findings of this study, following are several points that can be tackled later since we have not discussed in this paper:

1. A class of problems that we did not discuss but for which there are several interesting results, are problems in which jobs are to be processed through m non-identical processors and the processing time does not depend on the job.
2. Somewhat more interesting results exist for scheduling jobs when considering scheduling as a dynamic problem; one must determine the pattern of arrivals to the system. It is common for jobs to arrive according to some random process and queue up for service. Queuing theory and simulation may be useful as a tool for dealing with randomness of this type.
3. There are a number of actions that managers can be considered to minimize sequencing problem such as focusing on bottleneck operations, one can try to increase the capacity of the operations if that is possible or feasible, schedule the bottleneck operation first, and then schedule the non-bottleneck operations around the bottleneck operations. Thus, there is a need to develop a method for identifying the optimal schedule.
4. Finally, there is a need to study on an action that manager can consider minimizing scheduling problems that is, considering the lot splitting for large jobs. This probably works best when there are relating large differences in job timings.

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Table (1) Possible Priority Rules

Rules	Description	Type of rule
FCFS	First Come First Served	Local rule
SPT	Shortest Processing Time	Local rule
EDD	Earliest Due Date	Local rule
CR	Critical Ratio	Global rule
S/O	Slack per Operation	Global rule
RUSH	Emergency or Preferred Customer First	Local or Global

Table (2) Setting up Time Matrix

Job Number	Setup Time for M1	Conditions	Setup Time for M2	Conditions
1	ST_{11}	If Job 1 done first	ST_{12}	If Job 1 done first
2	ST_{21}	If Job 2 follows Job 1	ST_{22}	If Job 2 follows Job 1
3	ST_{31}	If Job 3 follows Job 2	ST_{32}	If Job 3 follows Job 2
:	:	:	:	:
:	:	:	:	:
:	:	:	:	:
N	ST_{N1}	If Job N follows Job N-1	ST_{N2}	If Job N follows Job N-1

Table (3) Data for Jobs and Processing Time

Job Number	Processing Time (Hr) for Vertical Cutting Machine	Processing Time (Hr) for Circular Cutting Machine
1	20	4
2	10	12
3	3	5
4	10	8
5	5	6
6	2	12
7	8	4
8	7	10
9	3	6
10	4	1

Table (4) Job's Setup time (minutes) on Vertical Cutting Machine

Jobs	1	2	3	4	5	6	7	8	9	10
1	5	18	13	24	18	20	15	19	15	1
2	15	18	10	4	17	20	17	25	18	29
3	16	20	13	15	18	19	15	30	10	15
4	10	11	20	16	12	25	3	22	12	8
5	20	28	17	35	28	5	16	6	30	23
6	15	18	10	17	15	2	20	3	5	9
7	2	7	15	28	17	9	11	3	25	8
8	30	6	14	10	25	17	12	13	15	15
9	9	2	17	1	9	9	20	25	30	7
10	9	2	18	15	7	33	14	45	19	33

Table (5)Job's Setup time (minutes) on Circular Cutting Machine

Jobs	1	2	3	4	5	6	7	8	9	10
1	5	25	18	30	15	12	13	10	12	15
2	9	15	20	30	8	33	17	25	14	19
3	17	25	29	25	11	18	25	17	18	27
4	12	30	25	19	28	22	2	7	17	30
5	5	8	16	20	25	15	31	17	17	22
6	7	25	5	14	20	19	10	9	13	2
7	6	1	4	5	10	8	9	12	16	4
8	9	20	21	18	9	12	25	18	7	19
9	10	15	17	13	12	18	20	25	11	32
10	7	3	8	5	17	20	8	45	5	15

Table (6) Calculation of Setup time by Existing Sequence

Job No.	T(M1)	T(M2)	M1		M2		Setup Time		
			Ti	To	Ti	To	ST_1	ST_2	TST
1	20	4	0	20	20	24	5	5	10
2	10	12	20	30	30	42	18	25	43
3	3	5	30	33	42	47	10	20	30
4	10	8	33	43	47	55	15	25	40
5	5	6	43	48	55	61	12	28	40
6	2	12	48	50	61	73	5	15	20
7	8	4	50	58	73	77	20	10	30
8	7	10	58	65	77	87	3	12	15
9	3	6	65	68	87	93	23	7	30
10	4	1	68	72	93	94	7	20	27
	72	68				653	118	167	285

Mean Flow Time = 65.3

Table (7) Generation of four sequences

S1:	6	3	9	5	8	2	4	1	7	10
S2:	6	9	3	5	8	2	4	1	7	10
S3:	6	3	9	5	8	2	4	7	1	10
S4:	6	9	3	5	8	2	4	7	1	10

Table (8) Calculation of Setup Time for sequence S1

Job	T(M1)	T(M2)	Machine1		Machine2		Setup Time		
			Ti	To	Ti	To	ST_1	ST_2	TST
6	2	12	0	2	2	14	15	7	22
3	3	5	2	5	14	19	10	5	15
9	3	6	5	8	19	25	10	18	28
5	5	6	8	13	25	31	9	12	21
8	7	10	13	20	31	41	6	17	23
2	10	12	20	30	41	53	6	20	26
4	10	8	30	40	53	61	4	30	34
1	20	4	40	60	61	65	10	12	22
7	8	4	60	68	68	72	15	13	28
10	4	1	68	**72**	72	73	8	4	12
						454	**93**	**138**	**231**

Mean Flow Time = 45.4

Table (9) Calculation of Setup Time for sequence S2

Job	T(M1)	T(M2)	Machine1		Machine2		Setup Time		
			Ti	To	Ti	To	ST_1	ST_2	TST
6	2	12	0	2	2	14	15	7	22
9	3	6	2	5	14	20	5	13	18
3	3	5	5	8	20	25	17	17	34
5	5	6	8	13	25	31	18	11	29
8	7	10	13	20	31	41	6	17	23
2	10	12	20	30	41	53	6	20	26
4	10	8	30	40	53	61	4	30	34
1	20	4	40	60	61	65	10	12	22
7	8	4	60	68	68	72	15	13	28
10	4	1	68	**72**	72	**73**	8	4	12
						455	**104**	**144**	**248**

Mean Flow Time = 45.5

Table (10) Calculation of Setup Time for sequence S3

Job	T(M1)	T(M2)	Machine1		Machine2		Setup Time		
			Ti	To	Ti	To	ST_1	ST_2	TST
6	2	12	0	2	2	14	15	7	22
3	3	5	2	5	14	19	10	5	15
9	3	6	5	8	19	25	10	18	28
5	5	6	8	13	25	31	9	12	21
8	7	10	13	20	31	41	6	17	23
2	10	12	20	30	41	53	6	20	26
4	10	8	30	40	53	61	4	30	34
7	8	4	40	48	61	65	3	2	5
1	20	4	48	68	68	72	2	6	8
10	4	1	68	**72**	72	**73**	1	15	16
						454	**66**	**132**	**198**

Mean Flow Time = 45.4

Table (11) Calculation of Setup Time for sequence S4

Job	T(M1)	T(M2)	Machine1		Machine2		Setup Time		
			Ti	To	Ti	To	ST_1	ST_2	TST
6	2	12	0	2	2	14	25	7	32
9	3	6	2	5	14	20	5	13	18
3	3	5	5	8	20	25	17	17	34
5	5	6	8	13	25	31	18	11	29
8	7	10	13	20	31	41	6	17	23
2	10	12	20	30	41	53	6	20	26
4	10	8	30	40	53	61	4	30	34
7	8	4	40	48	61	65	3	2	5
1	20	4	48	68	68	72	2	6	8
10	4	1	68	**72**	72	**73**	1	15	16
						455	**87**	**138**	**225**

Mean Flow Time = 45.5

Table (12) Summary of Calculation of Setup Time

Sequence	Time to finish all jobs by M1	Time to finish all jobs by M2	Setup time for all jobs for M1	Setup time for all jobs for M2	Total Setup Time $Z=ST_1+ST_2$	Mean Flow Time
S1	**72**	**73**	**93**	**138**	**231**	**45.4**
S2	**72**	**73**	**104**	**144**	**248**	**45.5**
S3	**72**	**73**	**66**	**132**	**198**	**45.4**
S4	**72**	**73**	**87**	**138**	**225**	**45.5**
Existing Sequence	***72***	***94***	***118***	***167***	***285***	***65.3***
Reduction(%)	***0***	***21***	***52***	***35***	***87***	***30.4***

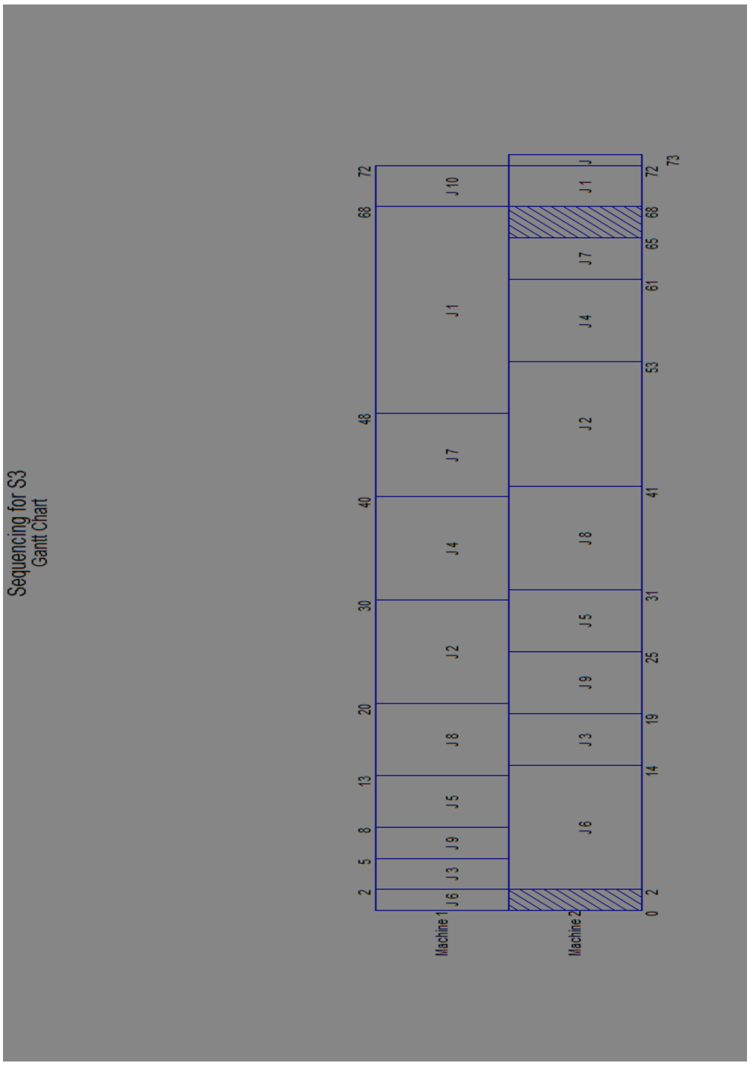

Figure (1) Gantt Chart for Sequencing S3