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# Production Scheduling to Minimize Makespan using Sequencing Total Work (TWK) Method and Campbell Dudek Smith (CDS) Algorithm

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**Abstract.** PT X is a manufacturing company that produces various types of piano instruments. The company applies a Make to Order (MTO) strategy because of its large production capacity with high product variety. Two working groups, cutting sizer and rotary press, were unable to reach their optimum conditions due to bottleneck in the cutting sizer working group. Appropriate scheduling is needed so that production activities are in accordance with daily production targets. In this research, a new scheduling system is proposed. The scheduling method used was sequencing Total Work (TWK) and continued with calculations using the Campbell Dudek Smith (CDS) algorithm. The total makespan in iteration 1 is 506,25 minutes, while makespan in iteration 2 is 583,49 minutes. The results of these calculation indicate that the proposed scheduling can overcome the problem of delays in delivery and fulfilment of daily production target.

## 1. Introduction

Proper production scheduling is needed by companies in order to reduce unproductive time of a production system. In production planning, companies are often faced with production scheduling problems [1]. PT X is a manufacturing company that produces piano instruments, types of Grand Piano (GP) and Upright Piano (UP). The company applies Make to Order (MTO) strategy because of its large production capacity and high product variety. In implementing MTO production strategy, the company often face scheduling problem, as a result of varied production objective and limited resources availability.

PT X has three working divisions, the division of wood working, painting and assembly, where each product type has a different production flow. The company implements a re-entrant flow-shop, which is a flow shop type that has characteristics job visiting a work station or machine more than once[2].

The current condition in PT X, time between processes is very high due to ineffective resource allocation. The cutting sizer section, as a supplier of rotary press machine, cannot reach its optimum condition. Delivery of the cabinet side and cabinet case are not in accordance with predetermined daily schedule. As a result, the rotary press machine is also unable to achieve its optimum condition. The result of one-month observation, the cutting sizer section is scheduled to produce 11.073 units but only 8.8841 is reached, or only 80% of the targeted number. In order to achieve production targets, the company implemented an overtime policy for operators.



The problem of ineffective resources allocation can be overcome by proper scheduling. Scheduling is a decision-making process that considers several limited resources to complete a set of activities within a predetermined period of time [3]. In this paper, a new scheduling is proposed so that production activities are carried out in accordance with the schedule and reduce non-productive time of available resources. The new scheduling is formulated using sequencing total work (TWK) method and Campbell Dudek Smith (CDS) algorithm.

The remainder of this paper is organised as follows: in Section 2, a literature review of production scheduling, sequencing, and Campbell Dudek Smith (CDS) algorithm is illustrated; in Section 3, the research method used is explained; in Section 4, the data collection process is presented, and calculation results are discussed; finally, in Section 6, conclusions and suggestions for future research are given.

## 2. Literature review

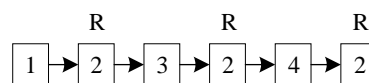
### 2.1. Production scheduling

Production scheduling is a process of allocating available resources and machinery to complete certain jobs, taking into account the limited number and capacity of the machine [4]. Through production scheduling, targeted product quantities can be produced with consideration of limited resources: machine capacity, time and cost availability. Scheduling performance can be measured based on four criteria: minimize completion time, maximize utilization, minimize work-in-process inventory, and minimize customer waiting time [5].

Throughput and due date are the two main considerations in production scheduling, i.e. throughput and due date [6]. There are five elements in production scheduling, i.e. (1) number of job ( $n$ ) to be processed; (2) number of machine ( $m$ ); (3) processing time (processing time of machine  $j$  to complete job  $i$ ); (4) completion time (completion time of all operation for job  $i$ ); and (5) makespan (completion time of all job scheduled) [7].

### 2.2. Flowshop

In flow shop scheduling,  $n$  job available will be processed on  $m$  machine with the similar sequence for every job [8]. The basic problem of flowshop scheduling is to determine a job sequence on every machine in accordance with certain provisions. Flowshop scheduling can be categorized in six patterns, i.e.: (1) pure flowshop; (2) skip flowshop; (3) compound flowshop; (4) reentrantflowshop; (5) finite queue flowshop; and (6) permutation flowshop [9]. The case study in this research applies a reentrantflowshop, where several machine can process a job more than once.



**Figure 1.** Reentrant flowshop

### 2.3. Sequencing

Sequencing is a process of determining the sequence and job priority based on the time of assignment, so that the tasks are processed systematically and proportionally according to the sequence and working time [10]. Priority rule is a guide for jobs sequencing by focusing on minimizing completion time and delays, increase utilization and the number of jobs in the system

There are eleven techniques in job sequencing, i.e. (1) random; (2) first come first serve (FCFS); (3) shortest processing time (SPT); (4) earliest due date (EDD); (5) critical ratio (CR); (6) least work remaining (LWR); (7) total work (TWK); (8) least total work (LWK); (9) fewest operation remaining (FOR); (10) slack time (ST); and (11) slack time per operation (ST/O) [11]. This research applies total

work (TWK) sequencing technique, where the priority of job sequencing is based on the number of operations.

#### 2.4. Campbell Dudek Smith (CDS) algorithm

The CDS algorithm is the development of Johnson's rule. Johnson's rule has limitations when used for scheduling that involve a large number of jobs that must be processed with multiple machines. Algorithm CDS is effective for both small and large problems[11]. The CDS algorithm consists of several steps as follows:

- 1) Take the first and last machine (other machines are considered non-existent), arrange the scheduling order using Johnson's rule.
- 2) Take machine 1, 2 and machine M, M-1, then combine the processing time between machine 1, 2 ( $t_{1,1}$ ,  $p_1$ ) and also the processing time of machine M, M-1 ( $t_{1,2}$ ,  $p_2$ ) using the following calculation. Arrange the scheduling order using Johnson's rule.

$$T_i, p_i = t_{i,1} + t_{i,2} \quad (1)$$

$$T_i, p_2 = t_{i,m-1} + t_{i,m} \quad (2)$$

- 3) Take machines 1,2,3 and machine M, M-1, M-2 and then combine the processing time between machine 1, 2, 3 ( $t_{i,p_2}$ ) using the following formula. Arrange the scheduling order using Johnson's rule.

$$T_i, p_i = \sum_{j=1}^M t_{i,j} \quad (3)$$

$$T_i, p_i = \sum_{j=M-2}^M t_{i,j} \quad (4)$$

- 4) Continue until the makespan and tardines of each machine is evaluated using the following calculation:

$$T_i, p_i = \sum_{j=1}^{M-1} t_{i,j} \quad (5)$$

$$T_i, p_i = \sum_{j=2}^M t_{i,j} \quad (6)$$

- 5) For each scheduling, calculate the makespan and chose the scheduling with the smallest makespan.

### 3. Research method

In this paper, a series of production processes at PT X, which are manufacturer of two types of piano instruments: Grand Piano (GP) and Upright Piano (UP), are used as research objects.

Research data can be classified into two types of data: primary and secondary data. Observation and interview are the methods used for primary data collection. While secondary data was collected using literature studies. Observations are carried out directly on production activities to identify problems that occur in the production floor and to obtain quantitative data. Interviews for all levels of workers: managers and operators, intended to obtain data that cannot be obtained through direct observation. Finally, in the literature studies, data was gathered regarding the company's historical data, and other references such as books and journals.

The first step of data processing, the cabinet with the fastest cycle time is grouped using dispatching rule Total Work approach. Then, the CDS algorithm is applied to formulate the scheduling, until the makespan of each iteration is obtained. Finally, the calculation results are analysed by comparing the actual output of current schedule and the output of proposed schedule.

## 4. Result and discussion

### 4.1. Data collection and processing

The cutting sizer working group consists of three main processes: (1) cabinet width splitting using double sizer machine; (2) cabinet length cutting using double tenoner machine; and (3) cabinet width splitting into a smaller size using bench saw machine. The company has 1 double sizer machine, 1 double tenoner machine, and 2 bench saw machines. The daily production target of the cutting sizer working group is 97 types of cabinet.

Cycle time data was collected by direct observation on the production floor, then validated by expert judgment. Details of cycle time of each cabinet, UP and GP piano types, are as follows:

**Table 1.** Cycle time cabinet UP and GP piano

No.	Model	Cabinet	Double sizer	Double tenoner	Bench saw
1	B1 PE	Side Arm R/L	0.19	0.19	1.10
2	B1 PE	Side Board R/L	0.58	0.27	-
3	B1 PE	Pedal Rail	0.14	0.04	0.42
...	...	...	...	...	...
97	UP PART	L E G	0.14	0.32	0.50

Based on the cycle time data, normal time is calculated by multiplying cycle times with rating factors. Rating factor calculation is based on performance rating using Westinghouse factor. Normal time of each cabinet is shown in the following table:

**Table 2.** Normal time cabinet UP and GP piano

No	Model	Cabinet	Double sizer	Double tenoner	Bench saw
1	B1 PE	Side Arm R/L	0.23	0.21	1.26
2	B1 PE	Side Board R/L	0.68	0.29	-
3	B1 PE	Pedal Rail	0.16	0.04	0.47
...	...	...	...	...	...
97	UP PART	L E G	0.17	0.35	0.58

Finally, based on the allowance assumption, the standard time of each cabinet is calculated.

**Table 3.** Standard time cabinet UP and GP piano

No.	Model	Cabinet	Double sizer	Double tenoner	Bench saw
1	B1 PE	Side Arm R/L	7.24	6.52	39.56
2	B1 PE	Side Board R/L	21.50	9.27	-
3	B1 PE	Pedal Rail	5.11	1.36	14.92
...	...	...	...	...	...
97	UP PART	L E G	5.38	10.89	18.14

The production flow in the cutting sizer working group is different for each cabinet. The cabinet production process generally passes three types of machine: double sizer, double tenoner and bench saw. However, there are some cabinets that only pass 1 or 2 type of machines.

**Table 4.** Production flow for each cabinet

No	Model	Cabinet	Double size	Double tenoner	Bench saw
1	B1 PE	Side Arm R/L	1	2	3
2	B1 PE	Side Board R/L	1	2	-
3	B1 PE	Pedal Rail	1	2	3
...	...	...	...	...	...
97	UP PART	L E G	1	2	3

#### 4.2 Implementation of TWK method and CDS algorithm

Based on the cycle time data, the first step is sequencing the cabinet based on the priority level in the production process. Sequencing applies the TWK method, where the cabinet with the same production flow will be grouped into one group. After obtaining the production group, the next step is the calculation of  $n$  iterations using CDS algorithm. In this case study, the number of iterations needed is 2 iterations, based on the formula  $m-1$ , where  $m$  is the number of machines.

**Table 5.** Result of CDS algorithm – iteration 1

Sequence	Deviation	Min	Code	Cabinet	$t_{j,1}^1$	$t_{j,2}^1$
1	6.29	0.11	BK	Hinge Strip	0.11	6.40
2	0.68	0.35	BJ	Pedal Rail	0.35	1.03
3	0.68	0.35	BV	Pedal Rail	0.35	1.03
...	...	...	...	...	...	...
96	2.34	-	CK	Bench Top	2.34	-
97	1.64	-	CJ	Bottom Frame	1.64	-

**Table 6.** Result of CDS algorithm – iteration 2

Sequence	Deviation	Min	Code	Cabinet	$t_{j,1}^1$	$t_{j,2}^1$
1	6.29	0.21	BK	Hinge Strip	0.21	6.50
2	0.68	0.57	BJ	Pedal Rail	0.57	1.25
3	0.68	0.57	BV	Pedal Rail	0.57	1.25
...	...	...	...	...	...	...
96	2.34	-	CK	Bench Top	2.34	-
97	1.64	-	CJ	Bottom Frame	1.64	-

After sequencing the cabinet using the TWK method and the iteration using the CSD algorithm, the next step is makespan calculation. There are two makespan calculations based on the number of iterations performed. Based on the results of makespan calculations, it can be determined the time needed by the work station to produce the entire cabinet.

The calculation results of 2 iterations, makespan in iteration 1 is 506,25 minutes and makespan in iteration 2 is 583,49 minutes. In the iteration 1, to produce 97 types of cabinets with the number of cabinets in accordance with the daily production schedule, it can be completed for 8 working hours and 46 minutes overtime. Whereas in the iteration 2, to produce the same amount, it takes 8 working hours plus 2 hours during overtime.

The makespan of proposed scheduling are obtained by the scenario of using 2 bench saw machines at the same time. Current production activities, only 1 bench saw machine is used, while 1 other machine is in standby position and is used when the main machine is in maintenance. On the proposed

scheduling, the production workload of the bench saw machine is divided equally for machine. As a result, the bottleneck that previously occurred in the cutting size working group can be overcome

**Table 7.** Makespan Calculation – Iteration 1

Sequence	Cabinet	Double sizer		Double tenoner		Bench saw		Bench saw 2	
		Start	Stop	Start	Stop	Start	Stop	Start	Stop
1	Hinge Strip	1.5	2.51	9.23	10.06	3.68	8.81		
2	Hinge Strip	4.01	5.64	15.50	16.96			6.81	15.08
3	Key Slip	7.14	8.96	7.14	8.96	10.12	21.63		
...	...	...	...	...	...	...	...	...	...
96	Top frame Side	497.85	501.29						
97	Top Frame	502.79	506.24						

**Table 8.** Makespan Calculation – Iteration 2

Sequence	Cabinet	Double sizer		Double tenoner		Bench saw		Bench saw 2	
		Start	Stop	Start	Stop	Start	Stop	Start	Stop
1	Hinge Strip	1.5	1.61	9.60	9.70	2.78	9.18		
2	Pedal Rail	3.11	3.47	3.11	3.47			4.63	5.66
3	Pedal Rail	4.97	5.32	4.97	5.32			6.83	7.86
...	...	...	...	...	...	...	...	...	...
96	Bench Top	578.01	580.35						
97	Bottom Frame	581.85	583.49						

## 5. Conclusion

Based on the result of the study, a combination of TWK method and CDS algorithm can produce a proposed scheduling that overcomes the tardiness of delivery. The proposed scheduling can be carried out if the workload of bench saw 1 machine is divided equally with the bench saw 2 machine. Future research recommendation is to consider maintenance schedules of all machines in scheduling. Through this recommendation, the unplanned breakdown of machinery can be avoided and the production process can run smoothly.

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