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THE SELECTION OF PROCESS SEQUENCE FOR MULTI MACHINE ARRANGED IN SERIES IN THE JOB SHOP INDUSTRY

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Abstract

PT. KOP operates within the oil and gas drilling sector, utilizing job shop production scheduling. The company produces 4 primary product types, employing 2 identical machines operated in parallel, as is common in the job shop industry. However, production planning faces challenges, notably delivery delays stemming from inefficient scheduling, indicated by high work-in-process inventory and machine tooling availability issues. This research proposes a series-based machine scheduling method, evaluating dispatching methods such as SPT (Shortest Processing Time), LPT (Longest Processing Time), and the Johnson algorithm. Results demonstrate that the Johnson method outperforms SPT and LPT, minimizing delay times to 1 hour in the first week, 16 hours in the second, 48 hours in the third, and 86 hours in the fourth. By arranging machines in series, tooling requirements are reduced by 50%. Specifically, series machines only require 4 tooling per product, while parallel machines require 8.

Keywords: *Dispatching; LPT; Johnson Algorithm; Series; SPT*

INTRODUCTION

In today's competitive landscape, many industrial enterprises strive for exceptional outcomes to ensure customer satisfaction and minimize disappointment. Maintaining product quality is paramount for business success as it directly impacts customer happiness. Timely delivery also plays a crucial role in customer satisfaction. One of the significant challenges faced by organizations is imprecise production scheduling, resulting in frequent product delivery delays. Implementing an effective production scheduling procedure is essential to ensure timely order fulfillment and minimize these delays (Mansouri, Golmohammadi and Miller, 2019).

The "Scheduling" entails arranging and organizing the sequence of tasks or operations within a production line to be performed across multiple machines. Meanwhile, "processing time" refers to the duration required to execute an activity or operation, which involves allocating specific resources within a predefined timeframe (Golmohammadi and Mansouri, 2015). The challenge of scheduling in dynamic job shops revolves around creating schedules across multiple machines using dispatching rules. The choice of dispatching rule depends on the scheduling objective. Various time-based objectives are linked with scheduling (Holthaus and Rajendran, 2000; Hildebrandt, Heger and Scholz-Reiter, 2010; Branke, Hildebrandt and Scholz-Reiter, 2015).

PT. KOP operates in the oil and gas drilling sector and offers 4 distinct products. The company utilizes 2 machines arranged in parallel for production, with each product completing its manufacturing process across both machines with two setups. Unfortunately, PT. KOP frequently encounters delivery delays stemming from inadequate production scheduling. The company's production process involves a set of identical machines, each assigned to manufacture a specific product. Machine one is dedicated to completing one product, while machine two is responsible for producing another product. These machines operate independently and are not synchronized during the production process (Lin and Huang, 2021). Despite using two identical machines in the production process, the company often faces delays of one to two weeks in product delivery. This delay arises from the necessity to dispatch items in pairs, which is not fulfilled due to incomplete production. This inadequacy stems from improper implementation of the production scheduling technique. To rectify this issue, organizations must establish an appropriate dispatching rule to effectively manage scheduling (Mönch *et al.*, 2005). In production scheduling, organizations often resort to random techniques, whereas in product delivery, they tend to operate in pairs. For example, product delivery companies may handle one to two products or three to four products simultaneously (Davari *et al.*, 2020).

The aim of production scheduling is to reduce delay time from specified deadlines to meet customer demands. It also seeks to minimize the total processing time of all jobs and improve machine efficiency while reducing idle time (Grundstein, Freitag and Scholz-Reiter, 2017; Irwan, 2020). Dispatching rules comprise a set of guidelines used in scheduling operations to establish the sequence in which jobs are processed on individual machines. Priorities are assigned to each job in the queue to determine this order (Sharda, 2013).

The FCFS (First-Come, First-Served) dispatching rule is widely used in production scheduling and order management. It prioritizes orders or jobs based on their arrival time, ensuring that those received first are processed first. Conversely, the SPT (Shortest Processing Time) rule is another method employed in production scheduling. It prioritizes orders or jobs based on their processing times, giving precedence to those with the shortest duration. (Jayamohan and Rajendran, 2000; Shady *et al.*, 2021).

The Johnson method is a technique in production and operations management employed to identify the most efficient sequence of tasks for executing the production process (Pinedo, 2008; Irwan, 2022). A Gantt chart is a type of bar chart that visually represents tasks and their corresponding timeframes. It is commonly used for project planning and coordinating various scheduled activities (Baker and Scudder, 1990; Supithak, Liman and Montes, 2010).

Research conducted by Waschneck *et al.* (2017) and Pfund, Mason and Fowler (2006), in the semiconductor industry highlights the continued use of dispatching rules for shop floor control in wafer manufacture. This system offers real-time capability and ease of comprehension for operators. Among the dispatching techniques, SPT stands out as particularly effective in reducing work-in-progress (WIP) on the machine. The research was conducted using the dispatching rule approach, specifically employing the SPT, LPT and the Johnson approach.

METHODOLOGY

The study took place at PT. KOP, a company operating in the oil and gas drilling industry. It focused on the machining operations, where the production of a single product involves two setup procedures. The data collected from the research include: (1) Production process time; (2) Setup; and (3) Demand. Then following the data analyze process based on the results of previous data processing attempts. The data processing and analysis involve several steps as describes in Table 1.

Table 1. Data Processing and Analysis Step

Steps	**Description**
Data processing	Processing the data to establish a production scheduling sequence using the Shortest Processing Time (SPT), Longest Processing Time (LPT), and Johnson methods to determine delivery times
Gantt Chart Generating	Generating a Gantt chart from the data obtained using the three methods. This chart serves as a planning tool for resource scheduling and time allocation
Select suitable method	Identifying the most suitable dispatching rules among the three methods (SPT, LPT, and Johnson) for scheduling at PT. KOP and understanding tooling utilization

Table 2 displays the order data for the month along with the corresponding due date. Furthermore, the manufacturing time and setup time are display in Table 3.

Table 2. Demand and Due Data (Hours)

Data		Week 1		Week 2		Week 3		Week 4	
		Demand	Due	Demand	Due	Demand	Due	Demand	Due
Product 1	Cust# 1		144	2	288		432	2	576
	Cust# 2	2							
	Cust# 3			4		4		4	
	Cust# 4	2				2			
	Total	4	144	6	288	6	432	6	576
Product 2	Cust# 1		144	2	288		432	3	576
	Cust# 2	4							
	Cust# 3			4		5		4	
	Cust# 4	4				2			
	Total	8	144	6	288	7	432	7	576
Product 3	Cust# 1	1	144		288	2	432	1	576
	Cust# 2			2		1		1	
	Cust# 3	1		2		1			
	Cust# 4	1		1				2	
	Total	3	144	5	288	4	432	4	576
Product 4	Cust# 1	1	144		288	2	432	1	576
	Cust# 2			1		1		1	
	Cust# 3	1		1		1			
	Cust# 4	1		1					
	Total	3	144	3	288	4	432	2	576

Table 3. Data Processing Time and Setup

No	Item	1st Process (Hours)		2nd Process (Hours)	
		Setup	Process	Setup	Process
1	Product 1	2	7	2	10
2	Product 2	1	3	1	6
3	Product 3	1	3	1	6
4	Product 4	2	8	2	11

Current Schedule

The current schedule algorithm prioritizes the execution of tasks based on their arrival order, ensuring that the earliest arriving task is processed first. The production process adheres to the FCFS (First Come, First Served) rule, wherein the production sequence extends from the first week to the fourth week, aligning with the product sequence 1-2-3-4. The computation of flow time is illustrated in Table 4.

Table 4. Data Current Schedule – Job Shop

Machine	Week 1		Week 2		Week 3		Week 4	
	Seq#	Plan	Seq#	Plan	Seq#	Plan	Seq#	Plan
#1	1	4	1	6	1	6	1	10
	2	8	2	6	2	7	2	6
#2	3	3	3	5	3	4	3	6
	4	3	4	3	4	4	4	11

The sequential arrangement of the manufacturing process for obtaining flow time data using FCFS scheduling policy is presented in Table 5.

Table 5. Flow Time Machine Schedule using FCFS

M	Week 1 (144)				Week 2 (288)				Week 3 (342)				Week 4 (576)			
	Seq#	Req	F_t	Late	Seq#	Req	F_t	Late	Seq#	Req	F_t	Late	Seq#	Req	F_t	Late
#1	1_1	30	30	0	1_1	44	190	0	1_1	44	352	0	1_1	44	523	0
	1_2	42	72	0	1_2	62	252	0	1_2	62	414	0	1_2	62	585	9
	2_1	25	97	0	2_1	19	271	0	2_1	22	436	4	2_1	22	607	31
	2_2	69	146	2	2_2	37	308	20	2_2	43	479	47	2_2	43	650	74
#2	3_1	10	10	0	3_1	16	106	0	3_1	13	211	0	3_1	13	329	0
	3_2	19	29	0	3_2	31	137	0	3_2	25	236	0	3_2	25	354	0
	4_1	26	55	0	4_1	26	163	0	4_1	34	270	0	4_1	34	388	0
	4_2	35	90	0	4_2	35	198	0	4_2	46	316	0	4_2	46	434	0

From the data provided in the table, it's clear that implementing the FCFS strategy in production planning at the company results in delays. In the first week, there's a 2-hour delay observed for product #2 on machine #1. In the second week, there's a delay of 20 hours for producing product #2. Product #2 encounters a delay of 51 hours in the third week. In the fourth week, both product #1 and product #2 experience delays, amounting to 9 hours and 105 hours respectively, compared to the scheduled timeframe.

Shortest Processing Time (SPT)

Afterwards, machine scheduling will be conducted sequentially following a priority order determined by the SPT (Shortest Processing Time) method. Scheduling jobs based on SPT calculations prioritizes those with the shortest production processing time for completion. The following table illustrates the computation of the scheduling order using the SPT rule. Table 6 demonstrates the sequence of processes for the demand over a four-week period, employing the SPT approach.

Table 6. Prioritize Planning using SPT

Item	Sub Item	Week 1		Week 2		Week 3		Week 4	
		P_t	Total	P_t	Total	P_t	Total	P_t	Total
Prod #1	1_1	30	$72^{(3)}$	44	$106^{(4)}$	44	$106^{(4)}$	44	$106^{(4)}$
	1_2	42		62		62		62	
Prod #2	2_1	25	$74^{(4)}$	19	$56^{(2)}$	22	$65^{(2)}$	22	$65^{(2)}$
	2_2	49		37		43		43	
Prod #3	3_1	10	$29^{(1)}$	16	$47^{(1)}$	13	$38^{(1)}$	13	$38^{(1)}$
	3_2	19		31		25		25	
Prod #4	4_1	26	$61^{(2)}$	26	$61^{(3)}$	34	$80^{(3)}$	34	$80^{(3)}$
	4_2	35		35		46		46	

The results of the preceding calculations can be arranged in accordance with the SPT regulations, the order calculation is performed each week as follows:

a) First-week product scheduling sequence **3-2-1-4**

b) Second-week product scheduling sequence **3-2-4-1**

c) Third week product scheduling sequence **3-2-4-1**

d) Product **3-2-4-1** scheduling sequence for the fourth week.

Data flow time based on SPT principles, as shown in Table 7.

Table 7. Flow Time Machine Schedule using SPT

M	Week 1 (144)				Week 2 (288)				Week 3 (432)				Week 4 (576)			
	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late
#1	3_1	10	10	0	3_1	16	107	0	3_1	13	209	0	3_1	13	322	0
	2_1	25	35	0	2_1	19	126	0	2_1	22	231	0	2_1	22	344	0
	1_1	30	65	0	4_1	26	152	0	4_1	34	265	0	4_1	34	378	0
	4_1	26	91	0	1_1	44	196	0	1_1	44	309	0	1_1	44	422	0
#2	3_2	19	19	0	3_1	16	161	0	3_2	25	320	0	3_2	25	496	0
	2_2	49	68	0	2_2	37	198	0	2_2	43	363	0	2_2	43	539	0
	1_2	42	110	0	4_2	35	233	0	4_2	46	409	0	4_2	46	585	9
	4_2	35	145	1	1_2	62	295	7	1_2	62	471	39	1_2	62	647	71

Based on the data presented in the table, it is evident that the implementation of the SPT approach for production planning throughout the organization leads to delays specifically on machine #2. In the first week delay for 1 hour on last product, the second week there was a delay of 7 hours for product #4. In the third week, a delay of 39 hours has been observed to produce product #4. In the fourth week, there is a delay of 9 hours for product #2 and 71 hours for product #4 from capacity on the week limits.

Longest Processing Time (LPT)

Afterwards, machine scheduling will be conducted sequentially following a priority order determined by the LPT (Longest Processing Time) method. Scheduling jobs based on LPT calculations prioritizes those with the longest production processing time for completion. The following table illustrates the computation of the scheduling order using the LPT rule. Table 8 demonstrates the sequence of processes for the demand over a four-week period, employing the LPT approach.

Table 8. Prioritize Planning using LPT

Item	Sub Item	Week 1		Week 2		Week 3		Week 4	
		P_t	Total	P_t	Total	P_t	Total	P_t	Total
Prod #1	1_1	30	72(1)	44	106(1)	44	106(1)	44	106(1)
	1_2	42		62		62		62	
Prod #2	2_1	25	74(3)	19	56(3)	22	65(3)	22	65(3)
	2_2	49		37		43		43	
Prod #3	3_1	10	29(4)	16	47(4)	13	38(4)	13	38(4)
	3_2	19		31		25		25	
Prod #4	4_1	26	61(2)	26	61(2)	34	80(2)	34	80(2)
	4_2	35		35		46		46	

The results of the preceding calculations can be arranged in accordance with the SPT regulations, the order calculation is performed each week as follows.

e) First-week product scheduling sequence **1-4-2-3**

f) Second-week product scheduling sequence **1-4-2-3**

g) Third week product scheduling sequence **1-4-2-3**

h) Product **1-4-2-3**scheduling sequence for the fourth week.

Data flow time based on LPT principles, as shown in Table 9.

Table 9. Flow Time Machine Schedule using LPT

M	Week 1 (144)				Week 2 (288)				Week 3 (432)				Week 4 (576)			
	Seq #	Req .	F_t	Late	Seq#	Req.	F_t	Lat e	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late
#1	1_1	30	30	0	1_1	44	74	0	1_1	44	179	0	1_1	44	292	0
	4_1	26	56	0	4_1	26	100	0	4_1	34	213	0	4_1	34	326	0
	2_1	25	81	0	2_1	19	119	0	2_1	22	235	0	2_1	22	348	0
	3_1	10	91	0	3_1	16	135	0	3_1	13	248	0	3_1	13	361	0
#2	1_2	42	42	0	1_2	62	207	0	1_2	62	357	0	1_2	62	533	0
	4_2	35	77	0	4_2	35	242	0	4_2	46	403	0	4_2	46	579	3
	2_2	49	126	0	2_2	37	279	0	2_2	43	446	14	2_2	43	622	46
	3_2	19	145	1	3_1	16	295	7	3_2	25	471	39	3_2	25	647	71

Based on the data presented in the table, it is evident that the implementation of the LPT approach for production planning throughout the organization leads to delays

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specifically on machine #2. In the first week delay for 1 hour on last product, the second week there was a delay of 7 hours for product #3. In the third week, a delay of 39 hours has been observed to produce product #3 and 14 hours for product #2. In the fourth week, there is a delay happen on 3 product there is 3 hours for product #4, 46 hours for product #2 and 71 hours for product #3 from capacity on the week limits.

Johson Algorithm

The Johnson method entails computing the processing time required for each operation across all jobs. The aim is to determine the operation with the shortest processing duration. If the shortest operation occurs at the beginning of a job, it should be performed on the last machine in the production sequence. Conversely, if the shortest operation occurs at the end of a job, it should be executed on the first machine in the production sequence. Initially, the shortest operation is removed from the first machine in the production sequence. Then, the operation with the shortest processing time at that moment is identified. This process iterates until all operations have been completed.

Johnson algorithm for two-stage production schedule as follow: Divide the job's set into two disjoint subsets, Sub_1 and Sub_2; where $Sub_1 = \{J_i, p_{i1} \leq p_{i2}\}$ and $Sub_2 = \{J_i, p_{i1} > p_{i2}\}$. Order the jobs within Sub_1 in the non-decreasing order of p_{i1} and those in Sub_2 in the non-increasing order of p_{i2}. Sequence jobs in Sub_1 first, followed by Sub_2 (Benttaleb, Hnaien and Yalaoui, 2018). Please refer to Table 10 for specifics on the procedure for determining the sequence using the Johnson algorithm.

Table 10. Prioritize Planning using Johnson Algorithm

Item	Week 1		Week 2		Week 3		Week 4	
	Proc #1	Proc #2	Proc #1	Proc #2	Proc #1	Proc #2	Proc #1	Proc #2
Product 1	30 (4)	42	54 (3)	66	78 (3)	90	102 (3)	114
Product 2	25 (2)	49	73 (4)	97	121 (4)	145	169 (4)	193
Product 3	10 (1)	19	28 (1)	37	46 (1)	55	64 (1)	73
Product 4	26 (3)	35	44 (2)	53	62 (2)	71	80 (2)	89
Sequences	3-2-4-1		3-4-1-2		3-4-1-2		3-4-1-2	

The results of the preceding calculations can be arranged in accordance with the Johnson Algorithm, the order calculation is performed each week as follows.

a) First-week product scheduling sequence **3-2-4-1**
b) Second-week product scheduling sequence **3-4-1-2**
c) Third week product scheduling sequence **3-4-1-2**

d) Product **3-4-1-2** scheduling sequence for the fourth week.

Data flow time based on Johnson Algorithm, as shown in Table 11.

Table 11. Flow Time Machine Schedule using Johnson Algorithm

M	Week 1 (144)				Week 2 (288)				Week 3 (432)				Week 4 (576)			
	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late
#1	3_1	10	10	0	3_1	16	26	0	3_1	13	128	0	3_1	13	241	0
	2_1	25	35	0	4_1	26	52	0	4_1	34	162	0	4_1	34	275	0
	4_1	26	61	0	1_1	44	96	0	1_1	44	206	0	1_1	44	319	0
	1_1	30	91	2	2_1	19	115	0	2_1	22	228	0	2_1	22	341	0
#2	3_2	19	19	0	3_2	31	176	0	3_2	25	335	0	3_2	25	511	0
	2_2	49	68	0	4_2	35	211	0	4_2	46	381	0	4_2	46	557	9
	4_2	35	103	0	1_2	62	273	0	1_2	62	443	11	1_2	62	619	43
	1_2	42	145	1	2_2	37	310	22	2_2	43	486	54	2_2	43	662	86

Based on the data presented in the table, it is evident that the implementation of the Johnson algorithm approach for production planning throughout the organization leads to delays specifically on machine #2. In the first week delay for 1 hour on last product, the second week there was a delay of 22 hours for product #1. In the third week, a delay of 11 hours has been observed to produce product #4 and 54 hours for product #1. In the fourth week, there is a delay happen on product #4 about 43 hours and 86 hours on product #1.

RESULTS AND DISCUSSION

Based on the research results from the trial with three approaches incorporating completion time, work tardiness, and mean flow time calculations, it is discovered that SPT makes a greater contribution. Table 12 presents comprehensive data regarding delays that arise from the three dispatching techniques. This data is obtained by comparing the flowtime of each product with its respective due date upon completion on each machine. Delays are observed when the duration of the flowtime beyond the pre-established deadline for each individual product.

In Table 12, it is evident that the SPT method for scheduling machine #2 results in a 1-hour delay for product #4 in the first week. This delay extends into the second week, reaching 7 hours and impact to Product #1, and by the third week still happen on product #1 about 39 hours behind schedule. Finally, at the conclusion of the fourth week, there is 2 product impact for late delivery, that is product #4 about 9 hours behind schedule and product #1 about 71 hours behind the schedule. The SPT scheduling still better than another 2 model and current practice schedules done by Planners.

Table 12. Comparison of Tardiness Data

		Week 1 (144)				Week 2 (288)				Week 3 (342)				Week 4 (576)			
	M	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late	Seq#	Req.	F_t	Late
Current – Parallel	#1	1_1	30	30	0	1_1	44	190	0	1_1	44	352	0	1_1	44	523	0
		1_2	42	72	0	1_2	62	252	0	1_2	62	414	0	1_2	62	585	9
		2_1	25	97	0	2_1	19	271	0	2_1	22	436	4	2_1	22	607	31
		2_2	69	146	2	2_2	37	308	20	2_2	43	479	47	2_2	43	650	74
	#2	3_1	10	10	0	3_1	16	106	0	3_1	13	211	0	3_1	13	329	0
		3_2	19	29	0	3_2	31	137	0	3_2	25	236	0	3_2	25	354	0
		4_1	26	55	0	4_1	26	163	0	4_1	34	270	0	4_1	34	388	0
		4_2	35	90	0	4_2	35	198	0	4_2	46	316	0	4_2	46	434	0
SPT	#1	3_1	10	10	0	3_1	16	107	0	3_1	13	209	0	3_1	13	322	0
		2_1	25	35	0	2_1	19	126	0	2_1	22	231	0	2_1	22	344	0
		1_1	30	65	0	4_1	26	152	0	4_1	34	265	0	4_1	34	378	0
		4_1	26	91	0	1_1	44	196	0	1_1	44	309	0	1_1	44	422	0
	#2	3_2	19	19	0	3_1	16	161	0	3_2	25	320	0	3_2	25	496	0
		2_2	49	68	0	2_2	37	198	0	2_2	43	363	0	2_2	43	539	0
		1_2	42	110	0	4_2	35	233	0	4_2	46	409	0	4_2	46	585	9
		4_2	35	145	1	1_2	62	295	7	1_2	62	471	39	1_2	62	647	71
LPT	#1	1_1	30	30	0	1_1	44	74	0	1_1	44	179	0	1_1	44	292	0
		4_1	26	56	0	4_1	26	100	0	4_1	34	213	0	4_1	34	326	0
		2_1	25	81	0	2_1	19	119	0	2_1	22	235	0	2_1	22	348	0
		3_1	10	91	0	3_1	16	135	0	3_1	13	248	0	3_1	13	361	0
	#2	1_2	42	42	0	1_2	62	207	0	1_2	62	357	0	1_2	62	533	0
		4_2	35	77	0	4_2	35	242	0	4_2	46	403	0	4_2	46	579	3
		2_2	49	126	0	2_2	37	279	0	2_2	43	446	14	2_2	43	622	46
		3_2	19	145	1	3_1	16	295	7	3_2	25	471	39	3_2	25	647	71
Johnson	#1	3_1	10	10	0	3_1	16	26	0	3_1	13	128	0	3_1	13	241	0
		2_1	25	35	0	4_1	26	52	0	4_1	34	162	0	4_1	34	275	0
		4_1	26	61	0	1_1	44	96	0	1_1	44	206	0	1_1	44	319	0
		1_1	30	91	2	2_1	19	115	0	2_1	22	228	0	2_1	22	341	0
	#2	3_2	19	19	0	3_2	31	176	0	3_2	25	335	0	3_2	25	511	0
		2_2	49	68	0	4_2	35	211	0	4_2	46	381	0	4_2	46	557	9
		4_2	35	103	0	1_2	62	273	0	1_2	62	443	11	1_2	62	619	43
		1_2	42	145	1	2_2	37	310	22	2_2	43	486	54	2_2	43	662	86

CONCLUSIONS

The findings from the research conducted on three dispatching strategies for scheduling a job shop when machine set as series has been give positive contribution on tardiness. Based on research for 2 machine identical set as series a method selection for priority sequence is SPT. That may still can be improve further when research more deep using optimization through simulation.

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