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Integration of lot sizing and scheduling models to minimize production cost and time in the automotive industry

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ABSTRACT

Lot planning and production scheduling are important processes in the manufacturing industry. This study is based on the case study of automotive spare parts manufacturing firm (Firm-A), which produces various products based on customer demand. Several complex problems have been identified due to different production process flows for different products with different machine capability considerations at each stage of the production process. Based on these problems, this study proposes three integrated models that include lot planning and scheduling to minimize production costs, production times, and production costs and time simultaneously. These can be achieved by optimizing model solutions such as job order decisions and production quantities on the production process. Next, the genetic algorithm (GA) and the Taguchi approach are used to optimize the models by finding the optimal model solution for each objective. Model testing is presented using numerical examples and actual case data from Firm-A. The model testing analysis is performed using Microsoft Excel software to develop a model based on mathematical programming to formulate all three objective functions. Meanwhile, GeneHunter software is used to represent the optimization process using GA. The results show production quantity and job sequence play an essential role in reducing the cost and time of production by Rp 42.717.200,00 and 31392.82 minutes (65.4 days), respectively. The findings of the study contribute to the production management of Firm-A in helping to make decisions to reduce the time and costs of production strategically, where it provides a guideline for complex production activities.

1. Introduction

Production planning in the manufacturing industry is an essential implementation before doing the actual production process. The main problems in production planning are machine availability, machine capacity, production time, capacity planning, and production process costs (Hu et al. 2017; Zhao et al. 2019; Han et al. 2019; Chong & Asih, 2015).

The main problem for each production plan is to determine the lot size for each product. Lot sizing can be defined as the decision of the production quantity of a particular product produced by a specific machine in a single production process (Almeder et al. 2014; Almada-Lobo et al. 2010; Clark et al. 2014; Leuveano et al., 2014; Rahman et al., 2015; Rahman et al., 2014). Lot sizing problems are often associated with efficient production planning for a product. Efficient production planning is achieved by solving lot allocation issues based on the demand that needs to be met and the availability of inventory stock (Almada-Lobo et al. 2010). Therefore, the purpose of lot sorting is to minimize production costs by determining the optimal production quantity (Ramezanian & Saidi 2013).

Next, scheduling is related to the determination of different types of jobs in the production process for single or multiple machining in a particular sequence (Pinedo 2012). According to (Pinedo 2012), scheduling is described as the planning of performing several activities in a given time, where the activity is related to the distribution of resources such as workers, machinery, and materials. The purpose of scheduling is to minimize production time by determining the optimal order of work (Liu, Wang, & Chu, 2013). Operating scheduling problems need to specialize in each type of work on a particular machine and also determine the sequence for each machine involved.

The problem of lot sorting and scheduling becomes more critical when production costs, inventory costs, and processing times are considered simultaneously. This affects the decision of production quantity and work sequence of each product in the production planning process (Quadt & Kuhn 2007; Almada-Lobo et al. 2010). These decisions affect the total production costs and production process time. Therefore, in determining the optimal and effective production planning results, it is necessary to improve the total production cost and product production time (Rohaninejad, Kheirkhah, & Fattahi, 2015).

To meet the demand by customers, Firm-A requires planning on the production process in meeting the number of products available. To overcome these problems, Firm-A has proposed for the implementation of an inventory management system in meeting customer needs. This inventory management is related to the optimal production quantity decision in the production system at Firm-A. Some inventory related problems have been identified as follows: (1) Difficulty in determining the number of products that can result in inadequate product or product. (2) Lack of accurate techniques to estimate production quantities and cause the production of errors in estimates that affect firm performance. Therefore, this study aims to optimize the lot sizing and work sequence for each product to minimize production costs and times.

2. Research Methodology

Firm-A is a case study firm that has been selected in this study. It produces various machining spare parts products. The location of Firm-A is located in the area of Klaten, Yogyakarta, Indonesia. Firm-A adopts a job shop production system. Therefore, Firm-A is seen as an appropriate firm in the context of the study conducted.

The development of a dynamic lot sizing and scheduling model is shown in Figure 1. This model relates to the product production process to meet dynamic customer demands with different quantities at each period.

3. Problem Formulation

3.1. Lot sizing model

This study uses a dynamic lot sizing model scenario. This model relates to the product production process to meet dynamic customer demands with different quantities at each period. The mathematical model of the dynamic lot sizing model was developed, the notations are as follow.

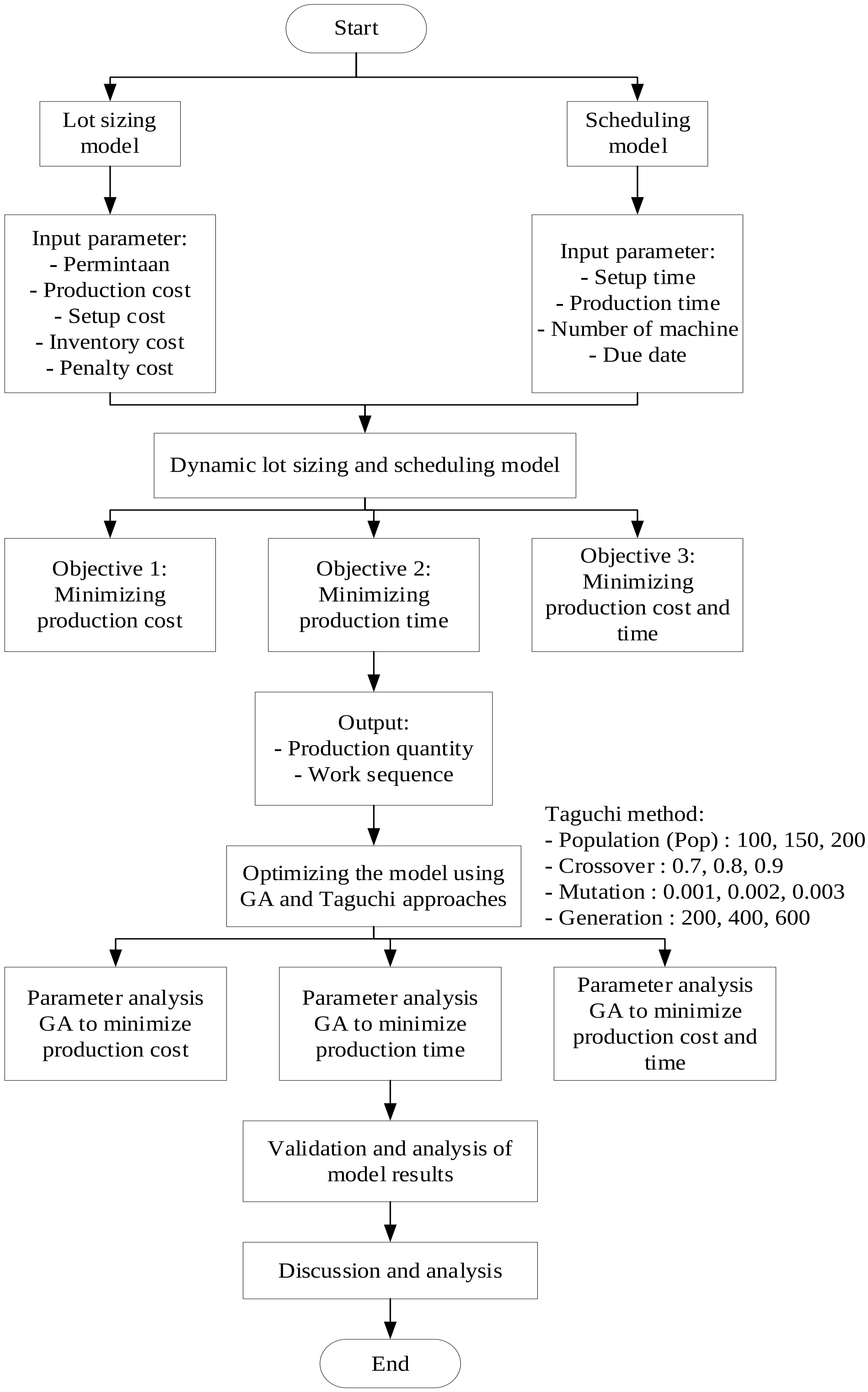

Figure 1. Model Development Flowchart

a	Number of product
d_1^a	Demand for product a in time t.
S_t^a	Setup cost for product a in time t.
Y_t^a	The binary variable, the value of 1 means product a that needs to be produced at period t, and the value of 0 is the opposite.
C_t^a	Production cost for each product a in time t
X_t^a	Production quantity for product a in all time
h_t^a	Inventory cost for product a in all time
I_t^a	Final inventory for product a in time t.
IL_t^a	Inventory units for product a that exceeds the warehouse capacity
CP_t^a	Penalty cost for product a in time t
Z	Total cost
$M_t^a = \sum_{t=1}^{T} d_1^a$	Total demand for product a in time t.

Then, the equation of lot sizing model to minimize the total cost for all products are presented below.

$$\text{Min } Z = \sum_{t=1}^{T}(S_t^a\,Y_t^a + C_t^a X_t^a + h_t^a I_t^a + IL_t^a CP_t^a) \tag{1}$$

The constraints:

$$X_t^a + I_{t-1}^a - I_t^a = d_t \quad (t = 1, \dots, T) \tag{2}$$

$$X_t^a \leq M_t^a Y_t^a \; (t = 1, \dots, T) \tag{3}$$

$$IL_t^a = \begin{cases} 0; & \text{jika } I_t^a \leq W_t^a; \\ I_t^a - W_t^a; & \text{jika } I_t^a > W_t^a; \end{cases} \tag{4}$$

$$Y_t^a \in \{0,1\} \quad (t = 1, \dots, T) \tag{5}$$

$$X_t^a, I_t^a, IL_t^a \geq 0 \quad (t = 1, \dots, T) \tag{6}$$

The objective function of equation (1) aims to minimize the setup cost, production cost, inventory cost, and inventory penalty costs that exceed warehouse capacity. The first equation in equation (1), the setup cost $S_t^a Y_t^a$ depends on the binary variable of the product produced. Then, the second equation $C_t^a X_t^a$ is the production cost which depends on the number of product produced. Next, the equation $h_t^a I_t^a$ is the inventory cost that is based on the final inventory time

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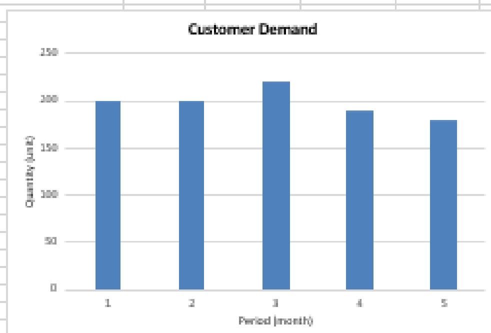
in each time. Then, the equation $IL_t^a CP_t^a$ is the inventory penalty cost that is based on the inventory that exceeds the warehouse capacity. The constraints are presented in equation 2-equation 6. Specifically, equation (4) is a formula for calculating inventory units that exceed the warehouse capacity. In this case, to achieve the objective of reducing production costs, then the production quantity X_t^a needs to be optimized.

The development of the lot sizing model was developed using Microsoft Excel® through spreadsheets. According to Barlow (2005), the spreadsheet approach is the use of interactive computers for an organization, analysis, and storage of data in a tabular form (tabular). In detail, a spreadsheet is often described as a matrix or grid cell form containing numbers encoded into columns or rows. Spreadsheets are widely accepted in the business world and do not specialize in specific techniques. Equation 1- equation 6 are applied in the spreadsheet as presented in Figure 2.

DESCRIPTION	PERIOD (MONTH)				
	1	2	3	4	5
CUSTOMER DEMAND	200	200	220	190	180



DESCRIPTION	PERIOD (MONTH)				
	1	2	3	4	5
PRODUCTION STATUS	1	1	1	0	0
PRODUCTION QUANTITY	[illegible]	275	242	0	179
CUMULATIVE PRODUCTION	[illegible]	369	411	191	180
CUSTOMER DEMAND	200	200	220	190	180
ON HAND INVENTORY	94	169	191	1	0

DESCRIPTION	PERIOD (MONTH)				
	1	2	3	4	5
INVENTORY CAPACITY	300	300	300	300	300
EXCESS PRODUCT	-	-	-	-	-
INVENTORY COST	[illegible]	1,000	1,000	1,000	1,000
ADDITIONAL INVENTORY COST	[illegible]	700	700	700	700
PENALTY FOR EXCESS PRODUCT	[illegible]	-	-	-	-
PENALTY FOR PRODUCT STOCKOUT	-	-	-	-	-
PRODUCTION COST	6,500	[illegible]	6,500	6,500	6,500
SETUP COST	500,000	500,000	500,000	500,000	500,000
TOTAL INVENTORY COST	94,000	169,000	[illegible]	1,000	-
TOTAL INVENTORY COST WITH ADDITIONS	94,000	169,000	[illegible]	1,000	-
TOTAL INVENTORY COST WITH PENALTIES	94,000	169,000	[illegible]	1,000	-
TOTAL PRODUCTION COST/UNIT	1,911,000	1,787,500	[illegible]	-	1,163,500
TOTAL SETUP COST	500,000	500,000	500,000	[illegible]	500,000
TOTAL PRODUCTION COST	2,693,000	2,794,500	2,646,000	[illegible]	[illegible]

Figure 2. The lot sizing model using spreadsheet in Microsoft Excel software

Table 1. Cell formulation for lot modeling model development using Microsoft Excel® software.

NO	CELL	FORMULA	MOVE TO
1	B34	The demand	C34:G34
2	B59	=IF(C63>D62,0,1)	C59:G59
3	B60	=IF(D59=1,D12,0)	C60:G60
4	B63	=C61-C62	C63:G63
5	B67	=IF(D63>D66,D63-D66,0)	C67:G67
6	B68	Inventory costs determined by Firm-A.	C68:G68
7	B69	Additional inventory costs determined by Firm-A.	C69:G69
8	B70	=C67*C69	C70:G70
9	B71	=IF(C63<0,1000000,0)	C71:G71
10	B74	=C63*C68	C74:G74
11	B75	=(C63*C68)+C70	C75:G75
12	B76	=C75+C71	C76:G76
13	B77	=IF(C59=1,$C$72*C12,0)	C77:G77
14	B78	=IF(C59=1,C59*C73,0)	C78:G78
15	B79	=SUM(C74:C78)	C79:G79

3.2. Scheduling model

Generally, the scheduling model is related to the output of lot sizing model, i.e. the production quantity. Next, a predetermined production quantity is scheduled to plan the production with minimum time. Therefore, the scheduling model is developed. According to Figure 3, the components of the scheduling model consist of job variables, machining parameters, setup time parameters and production time parameters

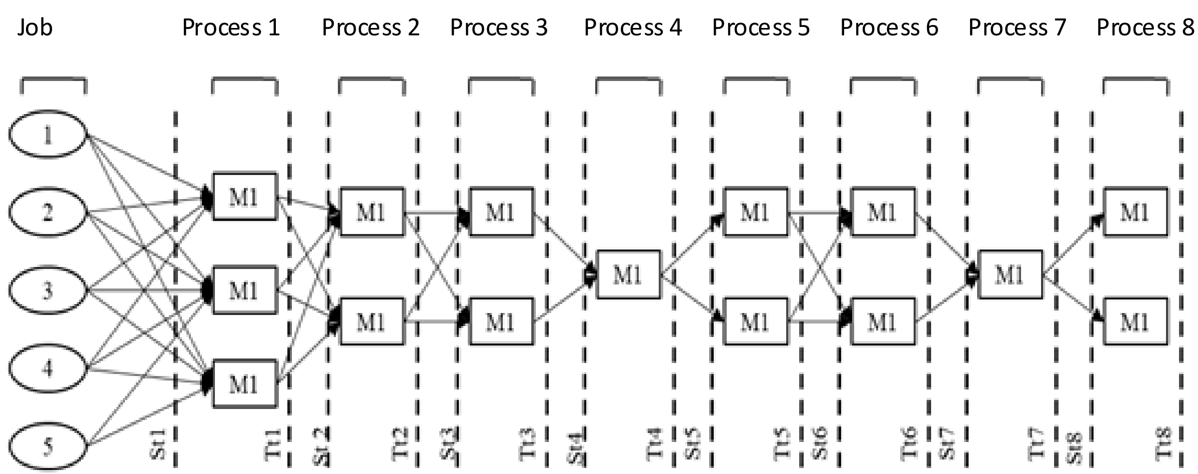


Figure 3. Scheme of production process flow in Firm-A

To develop a scheduling model, an illustration of the development of a scheduling model using a spreadsheet method based on Microsoft Excel® software can be shown in Figure 4. It presents

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a summary number representation for the scheduling process. Table 2 refers to the formulas in each row and column for the spreadsheet model.

	PRODUCT NAME	JOB	PROCESSING TIME LINE (M1)	DRILL (M2)	SCREW (M3)	SLOT (M4)	GRIND (M5)	PUTTY (M6)	SANDPAPER (M7)	PAINT (M8)		JOB	SETUP TIME LINE (M1)	DRILL (M2)	SCREW (M3)	SLOT (M4)	GRIND (M5)	PUTTY (M6)	NDPAP (M7)	PAINT (M8)
512	PULLEY B1 12"	1	17	0.6	1	2	2.5	1.4	0.5	2.1		1	2.8	0.5	0.3	1.1	0.5	0.1	0.7	1
513	PULLEY B2 8"	2	15		1.2	3	1.5	1.1	0.3	1.8		2	2		0.2	1.2	0.4	0.15	0.5	1.2
514	PULLEY B1 10"	3	14		0.9	1.9	2	1.2	0.9	2.2		3	2.7	0.4	0.4	1	0.7	0.2	0.3	0.9
515	PULLEY B1 20"	4	23	1.5	1.5	3.3	3.5	2.3	1.1	4		4	3.5	1	0.9	1.8	1	0.6	0.9	1.5
516	PULLEY B1 15"	5	19	0.9	0.8	2.3	1.6	1.7	0.7	3		5	3	0.8	0.8	1.5	0.4	0.12	0.4	1.2

	JOB	Machine 1 = 3 START	SETUP	TIMEFRAME	SETUP	FINISH	MACHINE	Machine 2 = 2 START	SETUP	TIMEFRAME	SETUP	FINISH	MACHI	Machine 3 = 2 START	SETUP	TIMEFRAME	SETUP	FINISH	MACHINE	Machine 4 = 1 START	SETUP	TIMEFRAME	SETUP	FINISH
520	CYCLE 1																							
521	1	0	2.8	17	19.8	19.8	1	19.8	0.5	0.6	1.1	20.9	1	20.9	0.3	1	1.3	22.2	1	22.2	1.1	2	3.1	25.3
522	3	0	2.7	14	16.7	16.7	2	16.7	0.4	1	1.4	18.1	2	18.1	0.4	0.9	1.3	19.4	2	25.3	1	1.9	2.9	28.2
523	5	0	3	19	22	22	3	22	0.8	0.9	1.7	23.7	1	23.7	0.8	0.8	1.6	25.3	1	28.2	1.5	2.3	3.8	32
524	2		2	15	17	36.8	1	36.8	0.6	0.8	1.4	38.2	2	38.2	0.2	1.2	1.4	39.6	2	39.6	1.2	3	4.2	43.8
525	4			23	26.5	43.2	2	43.2	1	1.5	2.5	45.7	1	45.7	0.9	1.5	2.4	48.1	1	48.1	1.8	3.3	5.1	53.2
526	CYCLE 2																							
527	1	22	2.8		19.8	41.8	3	41.8	0.5	0.6	1.1	42.9	2	42.9	0.3	1	1.3	44.2	2	53.2	1.1	2	3.1	56.3
528	3	36.8	2.7	14		53.5	1	53.5	0.4	1	1.4	54.9	1	54.9	0.4	0.9	1.3	56.2	1	56.2	1	1.9	2.9	59.1
529	5	43.2	3	19			2	65.2	0.8	0.9	1.7	66.9	2	66.9	0.8	0.8	1.6	68.5	2	68.5	1.5	2.3	3.8	72.3
530	2	41.8	2	15	17		3	58.8	0.6	0.8	1.4	60.2	1	60.2	0.2	1.2	1.4	61.6	1	72.3	1.2	3	4.2	76.5
531	4	53.5	3.5	23	26.5	80	1			1.5	2.5	82.5	2	82.5	0.9	1.5	2.4	84.9	2	84.9	1.8	3.3	5.1	90
532	CYCLE 3																							
533	1	65.2	2.8	17	19.8	85	2	85	0.5	0.6	1.1	86.1	1	86.1	0.3	1	1.3	87.4	1	90	1.1	2	3.1	93.1
534	3	58.8	2.7	14	16.7	75.5	3	75.5	0.4	1	1.4	76.9	2	76.9	0.4	0.9	1.3	78.2	2	93.1	1	1.9	2.9	96
535	5	80	3	19	22	102	1	102	0.8	0.9	1.7	103.7	1	103.7	0.8	0.8	1.6	105.3	1	105.3	1.5	2.3	3.8	109.1
536	2	85	2	15	17	102	2	102	0.6	0.8	1.4	103.4	2	103.4	0.2	1.2	1.4	104.8	2	109.1	1.2	3	4.2	113.3
537	4	75.5	3.5	23	26.5	102	3	102	1	1.5	2.5	104.5	1	104.5	0.9	1.5	2.4	106.9	1	113.3	1.8	3.3	5.1	118.4
538	CYCLE 4																							
539	1	102	2.8	17	19.8	121.8	1	121.8	0.5	0.6	1.1	122.9	2	122.9	0.3	1	1.3	124.2	2	124.2	1.1	2	3.1	127.3
540	3	102	2.7	14	16.7	118.7	2	118.7	0.4	1	1.4	120.1	1	120.1	0.4	0.9	1.3	121.4	1	127.3	1	1.9	2.9	130.2
541	5	102	3	19	22	124	3	124	0.8	0.9	1.7	125.7	2	125.7	0.8	0.8	1.6	127.3	2	130.2	1.5	2.3	3.8	134
542	2	121.8	2	15	17	138.8	1	138.8	0.6	0.8	1.4	140.2	1	140.2	0.2	1.2	1.4	141.6	1	141.6	1.2	3	4.2	145.8
543	4	118.7	3.5	23	26.5	145.2	2	145.2	1	1.5	2.5	147.7	2	147.7	0.9	1.5	2.4	150.1	2	150.1	1.8	3.3	5.1	155.2
544	CYCLE 5																							
545	1	124	2.8	17	19.8	143.8	3	143.8	0.5	0.6	1.1	144.9	1	144.9	0.3	1	1.3	146.2	1	155.2	1.1	2	3.1	158.3
546	3	138.8	2.7	14	16.7	155.5	1	155.5	0.4	1	1.4	156.9	2	156.9	0.4	0.9	1.3	158.2	2	158.3	1	1.9	2.9	161.2
547	5	12	3	19	22	167.2	2	167.2	0.8	0.9	1.7	168.9	1	168.9	0.8	0.8	1.6	170.5	1	170.5	1.5	2.3	3.8	174.3
548	2	143.8	2	15	17	160.8	3	160.8	0.6	0.8	1.4	162.2	2	162.2	0.2	1.2	1.4	163.6	2	174.3	1.2	3	4.2	178.5

Figure 4a. The development of the scheduling model in Microsoft Excel Software – part 1

	JOB	QUANTITY
513	1	294
514	2	209
515	3	241
516	4	143
517	5	293

	FINISH	MACHINE	Machine 8 = 2 START	SETUP	TIMEFRAME	SETUP	FINISH	MACHINE	PRODUCTION	CUMULATIVE	TOTAL
520	31	1	31	1	2.1	3.1	34.1	1	1	1	294
521	33.5	1	33.5	0.9	2.2	3.1	36.6	2	1	1	241
522	36.92	1	36.92	1.2	3	4.2	41.12	1	1	1	293
523	47.75	1	47.75	1.2	1.8	3	50.75	2	1	1	209
524	62.6	1	62.6	1.5	4	5.5	68.1	1	1	1	143
525											
526	62	1	62	1	2.1	3.1	65.1	2	1	2	294
527	64.5	1	68.1	0.9	2.2	3.1	71.2	1	1	2	241
528	77.22	1	77.22	1.2	3	4.2	81.42	2	1	2	293
529	80.45	1	80.45	1.2	1.8	3	83.45	1	1	2	209
530	99.4	1	99.4	1.5	4	5.5	104.9	2	1	2	143
531											
532	98.8	1	98.8	1	2.1	3.1	101.9	1	1	3	294
533	101.3	1	104.9	0.9	2.2	3.1	108	2	1	3	241
534	114.02	1	114.02	1.2	3	4.2	118.22	1	1	3	293
535	117.25	1	117.25	1.2	1.8	3	120.25	2	1	3	209
536	127.8	1	127.8	1.5	4	5.5	133.3	1	1	3	143
537											
538	133	1	133	1	2.1	3.1	136.1	2	1	4	294
539	135.5	1	135.5	0.9	2.2	3.1	138.6	1	1	4	241
540	138.92	1	138.92	1.2	3	4.2	143.12	2	1	4	293
541	149.75	1	149.75	1.2	1.8	3	152.75	1	1	4	209
542	164.6	1	164.6	1.5	4	5.5	170.1	2	1	4	143

Figure 4b. The development of the scheduling model in Microsoft Excel Software – part 2

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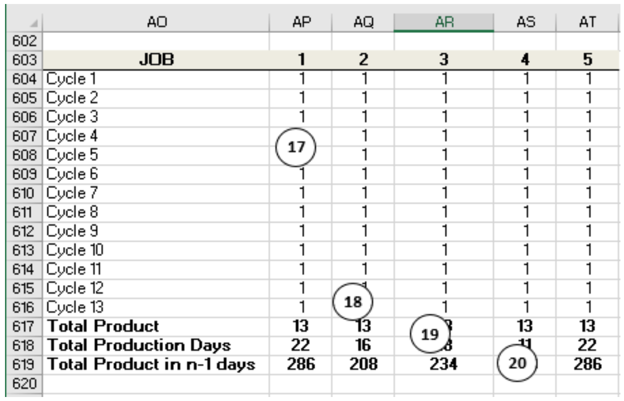
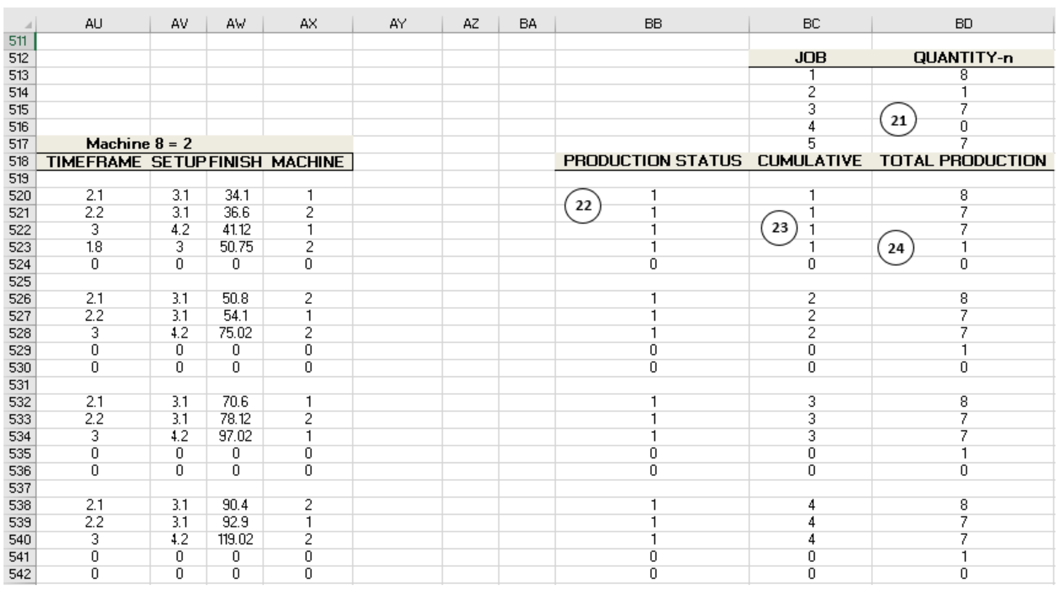


	AO	AP	AQ	AR	AS	AT
602						
603	**JOB**	**1**	**2**	**3**	**4**	**5**
604	Cycle 1	1	1	1	1	1
605	Cycle 2	1	1	1	1	1
606	Cycle 3	1	1	1	1	1
607	Cycle 4	[illegible]	1	1	1	1
608	Cycle 5	[illegible]	1	1	1	1
609	Cycle 6	1	1	1	1	1
610	Cycle 7	1	1	1	1	1
611	Cycle 8	1	1	1	1	1
612	Cycle 9	1	1	1	1	1
613	Cycle 10	1	1	1	1	1
614	Cycle 11	1	1	1	1	1
615	Cycle 12	1	1	1	1	1
616	Cycle 13	1		1	1	1
617	**Total Product**	**13**	**13**	[illegible]	**13**	**13**
618	**Total Production Days**	**22**	**16**	[illegible]	**11**	**22**
619	**Total Product in n-1 days**	**286**	**208**	**234**		**286**
620						

Figure 4c. The development of the scheduling model in Microsoft Excel Software – part 3



	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
511										
512									**JOB**	**QUANTITY-n**
513									1	8
514									2	1
515									3	7
516									4	0
517	**Machine 8 = 2**								5	7
518	**TIMEFRAME**	**SETUP**	**FINISH**	**MACHINE**				**PRODUCTION STATUS**	**CUMULATIVE**	**TOTAL PRODUCTION**
519										
520	2.1	3.1	34.1	1				1	1	8
521	2.2	3.1	36.6	2				1	1	7
522	3	4.2	41.12	1				1	1	7
523	1.8	3	50.75	2				1	1	1
524	0	0	0	0				0	0	0
525										
526	2.1	3.1	50.8	2				1	2	8
527	2.2	3.1	54.1	1				1	2	7
528	3	4.2	75.02	2				1	2	7
529	0	0	0	0				0	0	1
530	0	0	0	0				0	0	0
531										
532	2.1	3.1	70.6	1				1	3	8
533	2.2	3.1	78.12	2				1	3	7
534	3	4.2	97.02	1				1	3	7
535	0	0	0	0				0	0	1
536	0	0	0	0				0	0	0
537										
538	2.1	3.1	90.4	2				1	4	8
539	2.2	3.1	92.9	1				1	4	7
540	3	4.2	119.02	2				1	4	7
541	0	0	0	0				0	0	1
542	0	0	0	0				0	0	0

Figure 4d. The development of the scheduling model in Microsoft Excel Software – part 4

Table 2. Cell formulation for scheduling modeling model development using Microsoft Excel® software.

NO	CELL	FORMULA	MOVE TO
1	Index D512-L516	Processing time for each product in each machine	Index D512-L516
2	Index O512-L516	Setup time for each product in each machine	Index O512-L516
3	B522:B526	Work orders/sequences	B522:B526

NO	CELL	FORMULA	MOVE TO
4	C520	=IF(BB526=0,0,IF(OR(AND(BB526=1,H526=1,H522=0,H523=0,H524=0,H525=0),AND(BB526=1,H526=2,H522=1,H523=0,H524=0,H525=0),AND(BB526=1,H526=2,H522=0,H523=1,H524=0,H525=0),AND(BB526=1,H526=2,H522=0,H523=0,H524=1,H525=0),AND(BB526=1,H522=0,H523=0,H524=0,H525=1),AND(BB526=1,H526=3,H522=1,H523=2,H524=0,H525=0),AND(BB526=1,H526=3,H522=1,H523=0,H524=2,H525=0),AND(BB526=1,H526=3,H522=1,H523=0,H524=0,H525=2),AND(BB526=1,H526=3,H522=0,H523=0,H524=1,H525=2),AND(BB526=1,H526=3,H522=0,H523=1,H524=2,H525=0),AND(BB526=1,H526=3,H522=0,H523=1,H524=0,H525=2)),0,IF(OR(AND(BB526=1,H526=1,H522=1),AND(BB526=1,H526=2,H522=2),AND(BB526=1,H526=3,H522=3)),G522,IF(OR(AND(BB526=1,H526=1,H523=1),AND(BB526=1,H526=2,H523=2),AND(BB526=1,H526=3,H523=3)),G523,(IF(OR(AND(BB526=1,H526=1,H524=1),AND(BB526=1,H526=2,H524=2),AND(BB526=1,H526=3,H523=3)),G524,(IF(OR(AND(BB526=1,H526=1,H525=1),AND(H526=2,H525=2),AND(BB526=1,H526=3,H525=3)),G525,""))))))))	C522:C526
5	D520	=IF(BB526=0,0,INDEX($P$512:$W$516,B526,1))	D522:D526
6	E520	=IF(BB526=0,0,INDEX($E$512:$L$516,B526,1))	E522:E526
7	F520	=IF(BB526=0,0,E526+D526)	F522:F526
8	G520	=IF(BB526=0,0,C526+F526)	G522:G526
9	H520	=IF(BB526=0,0,IF(OR(AND(BB526=1,H522=0,H523=0,H524=0,H525=0),AND(BB526=1,H522=1,H523=2,H524=3,H525=0),AND(BB526=1,H522=1,H523=2,H524=0,H525=3),AND(BB526=1,H522=1,H523=0,H524=2,H525=3),AND(BB526=1,H522=0,H523=1,H524=2,H525=3)),1,IF(OR(AND(BB526=1,H522=0,H734=0,H524=0,H525=1),AND(BB526=1,H522=1,H523=2,H524=3,H525=1),AND(BB526=1,H522=0,H523=1,H524=0,H525=0),AND(BB526=1,H522=0,H523=0,H524=1,H525=0),AND(BB526=1,H522=1,H523=0,H524=0,H525=0)),2,IF(OR(AND(BB526=1,H522=1,H523=2,H524=0,H525=0),AND(BB526=1,H522=0,H523=1,H524=0,H525=2),AND(BB526=1,H522=0,H523=1,H524=2,H525=0),AND(BB526=1,H522=1,H523=0,H524=0,H525=2),AND(BB526=1,H522=1,H523=0,H524=2,H525=0),AND(BB526=1,H522=0,H523=0,H524=1,H525=2)),3,""))))	H522:G526
10	I520	=IF(BB526=0,0,IF(AND(BB526=1,N526=1,N524=1),MAX(M524,G526),IF(AND(BB526=1,N526=2,N524=2),MAX(M524,G526),IF(AND(BB526=1,N526=2,N523=2),MAX(M523,G526),IF(AND(BB526=1,N526=1,N523=1),MAX(M523,G526),IF(AND(BB526=1,N526=1,N522=1),MAX(M522,G526),IF(OR(AND(BB526=1,N522=0,N523=0,N524=0,N525=0,N526=1),AND(BB526=1,N522=0,N523=0,N524=0,N525=1,N526=2),AND(BB526=1,N522=0,N523=0,N524=1,N525=0,N526=2),AND(BB526=1,N522=0,N523=1,N524=0,N525=0,N526=2),AND(BB526=1,N522=1,N523=0,N524=0,N525=0,N526=2)),G526,0)))))))	I522:I526

NO	CELL	FORMULA	MOVE TO
11	J520	=IF(BB526=0,0,INDEX($P$512:$W$516,B526,2))	J522:J526
		The process from cell C520 is continued to cell AX520 with the same formula as before.	
12	BC514	Work orders/sequences parameter	
13	BD514	Production quantity	BD515:BD519
14	BB520	=IF(BD523>0,1,0)	BB522:BB526
		The process from the first cycle continues until the 13th cycle	
15	BC520	=IF(BB529=0,0,BB529+BC523)	BC522:BC526
		The process from the first cycle continues until the 13th cycle	
16	BD520	=INDEX($BD$515:$BD$519,B522,1)	BD522:BD526
		The process from the first cycle continues until the 13th cycle	
17	AP604	Total production of each product in each cycle	AP604:AP616
18	A0617	=SUM(AP604:AP616)	AP617:AT617
19	AO618	=ROUNDDOWN($BD$515/$AE$617,0)	AP618:AT618
20	AO619	=$AE$619*$AE$617	AP619:AT619
21	BD621	Remaining unfulfilled production quantity	BD622:626
22	BB628	=IF(BD631>0,1,0)	BB629:BB634
23	BC628	=IF(BB636=0,0,BB636+BC630)	BC629:BC634
24	BD628	=INDEX($BD$622:$BD$626,B631,1)	BD629:BD634

3.3. Taguchi method and Genetic Algorithm (GA)

By using the parameters stated in the previous subsection, the application of lot sizing and scheduling model is done. In this regard, the GA approach is used to solve model problems. The first step is to find the best GA parameters that produce a strong qualification value. This can be done using the Taguchi method. The use of the Taguchi method is to consider the L9 design that follows the orthogonal array (OA). The OA value is based on the GA parameter level shown in Table 3. By following OA, then the experimental design arrangement containing the GA parameter level is shown in Table 4.

Table 3. The GA parameter

PARAMETER	LEVEL		
	1	2	3
Population (Pop)	100	150	200
Crossover (P_c)	0.7	0.8	0.9
Mutation P_m)	0.001	0.002	0.003
Generation (G_n)	200	400	600

Table 4. Orthogonal array design for L9

ORTHOGONAL ARRAY	POPULATION ($\boldsymbol{Pop}$)	CROSSOVER ($\boldsymbol{P_c}$)	MUTATION ($\boldsymbol{P_m}$)	GENERATION ($\boldsymbol{G_n}$)
L1	100	0.7	0.001	200
L2	100	0.8	0.002	400
L3	100	0.9	0.003	600
L4	150	0.7	0.002	600
L5	150	0.8	0.003	200

ORTHOGONAL ARRAY	POPULATION (Pop)	CROSSOVER (P_c)	MUTATION (P_m)	GENERATION (G_n)
L6	150	0.9	0.001	400
L7	200	0.7	0.003	400
L8	200	0.8	0.001	600
L9	200	0.9	0.002	200

3. Results and Discussion

The developed models have their optimizations, i.e., the first model is to minimize the production cost, the second model is to reduce the production time, and the third one is to reduce production cost and time. The results are shown in Table 3.

Table 3. The results of the developed models

	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	TOTAL
Expiration date	23 days	23 days	24 days	22 days	19 days	-
Model 1	Exceeds (1 day)	Exceeds (2 day)	Fulfilled	Exceeds (1 day)	Fulfilled	4 days
Model 2	Fulfilled	Fulfilled	Fulfilled	Fulfilled	Fulfilled	0
Model 3	Fulfilled	Fulfilled	Fulfilled	Exceeds (1 day)	Fulfilled	1 day
Penalty of model 1	200000	400000	0	200000	0	800000
Penalty of model 2	0	0	0	0	0	0
Penalty of model 3	0	0	0	200000	0	200000
Cost of model 1 (in Rp)	11414300	12418700	4933600	7555200	5265800	41587600
Cost of model 2 (in Rp)	10661000	9345600	12440900	4716600	6696300	43860400
Cost of model 3 (in Rp)	9987100	10161900	10928900	6954300	4685000	42717200
Time of model 1 (in minute)	10143.25	10305.75	8095.1	8771.32	6280.5	43595.92
Time of model 2 (in minute)	8565.02	6758.02	9265.9	880.8	2905	28374.74
Time of model 3 (in minute)	8661.5	8073.4	9272.9	2136.22	3248.8	31392.82

The result of the first model shows the production is exceeded on the expiration date. The penalty cost is charged about Rp 200,000 per day and the total is Rp 800,000. However, the overall cost of the first model period shows the lowest value compared to other models. Next, the second model shows the successful completion of the product before the expiration date but has the highest production cost. Meanwhile, the third model indicates that there is a day delay in production but gives a cost value that is between the first model and the second model. This is an interesting problem for the management in making an appropriate decision evaluation in the selection of the desired approach.

The best production time is produced on the second model without any penalty for meeting the expiration date. Meanwhile, on the first model and the third model has a production time that exceeds the expiration date. Based on the production time function, only the second model shows the minimum production time. However, management will experience the highest increase in production costs. Management needs to be rational about the desired performance either in the form of profit or long-term relationships with customers. In this situation, the company has to suffer some losses, but at the same time, the company should maintain customer satisfaction based on the services offered to meet the demand based on the time set by the customer. This situation gives the advantage of creating a long-term relationship between suppliers and customers.

For the third model is able to reduce production costs and production time equally where the value of the function is between the first model and the second model. In this situation, the company needs to determine the primary goal of production. The third model is the researcher's recommendation to management in minimizing both functions, but it depends on the company in determining the appropriate results.

The purpose of the model can be achieved by determining optimal results on production quantities and job sequences to address the problem of lot allocation and scheduling simultaneously. Furthermore, model testing was performed using the GA method and the Taguchi method to find the best qualifying value representing production costs and minimum production times. Then, the best use of GA parameters can produce the best model performance results for each of the stated objectives. The results show that the best production cost and time performance can be shown through the third model, which is able to balance the two performance well.

4. Conclusion

This study aims specifically to improve the firm's performance in minimizing production costs and production times by implementing the method of developing a lot sizing models and scheduling models. The next developed model is optimized using the GA approach. The results show the comparison of production cost for the third model to the first model is 2.7%, and the third model to the second model is 2.69%. Meanwhile, the comparison of the production time of the third model to the first model is 38.87%, and the third model to the second model is 10.6%. Next, the minimum cost and production time can be achieved at Rp 42,717,200 and 31392.82 minutes (65.4 days). In conclusion, the third model has better production costs and time compared to the first and second models.

This study contributes specifically to provide views and decision guidance for management to make decisions in determining the optimal production quantity and sequence of work that is the minimum cost and production time as well as to achieve the target to meet customer demand within the allotted time. The optimal production quantity and sequence of work are determined by demand, production time, number of machines, and number of jobs. Therefore, the management of the firm needs to pay attention to the matter in preparation for the production operation.

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