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A GENETIC ALGORITHM APPROACH FOR SOLVING INBOARD OUTER FIXED LEADING EDGE-DRIVE RIB 1 PRODUCTION SCHEDULING AT PT DIRGANTARA INDONESIA

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ABSTRACT

The scheduling of production floor is a sophisticated problem which seeks the optimal task allocation to certain resources under a number of constraints.The use of optimization techniques facilitates the determination of acceptable solutions that considered optimized for a specific problem. This paper proposes production scheduling solution based on job priority in a Non-Deterministic Polynomial-time hard (NP-hard) problem. The case study was taken from the Spirit Aerosystem Project, particularly in the Inboard Outer Fixed Leading Egde - Drive Rib 1 component production process. The problem consists of finding the machine operations schedule, taking into account the precedence constraints. The main objective is to minimize total delays or tardiness. The genetic algorithm was employed to determine the optimized production scheduling solution. The parameter for genetic operators in this study consists of a roulette wheel selection, 1 elitist chromosome, partially-mapped crossover mutation and 1 point mutation. The termination condition was achieved when there has been no improvement in the population for 30 iterations.The results show that the algorithm is capable to generate optimum production schedule with minimum tardiness for the given problem.

Keywords: *Genetic algorithm, job shop problem, scheduling problem*

1. INTRODUCTION.

Industrial sectors always experience frequent changes and the incidence of unplanned disturbances, that make production plans quickly becomes obsolete and inapplicable. The solution to this problem requires a new methodology of optimization techniques, that not only capable of generating quality solutions, but also able to reduce the computation time. This paper studies the application of a genetic algorithm approach to determine production scheduling in PT Dirgantara Indonesia (PT DI). PT DI has several projects on its schedule, one of them is with Spirit Aerosytem Europe, which manufactures parts and components for an A320, A321 and A380 types of aircraft. Production process in this project are organized as flexible job shop under first come first serve (FCFS) rule. Under FCFS rule, job sequence list in PT DI Sprit Aerosystem is structured in accordance with the order of job arrival without paying much attention to the job due date or customer preference. Thereby, current production scheduling is fairly intuitive and heavily depending on experience, resulting in late delivery and inefficient resource utilization in the production floor. The traditional scheduling method often causes some orders to exceed the previously agreed delivery time. Figure 1 shows the late delivery rate of the production department. This figure tells that during 2013-2017 the average late delivery rate is 57.36%.

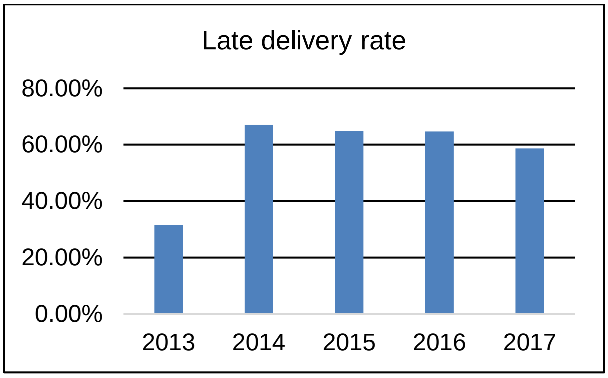

Fig. 1 Late delivery rate in PT DI Spirit Aerosystem

Figure 2 compares total planned throughputand actual throughput and shows that the amount of outstanding orders in PT DI Spirit Aerosystem is quite high.It becomes evident that in 2017 alone there were 50.79% of orders that experienced completion delays or late delivery.

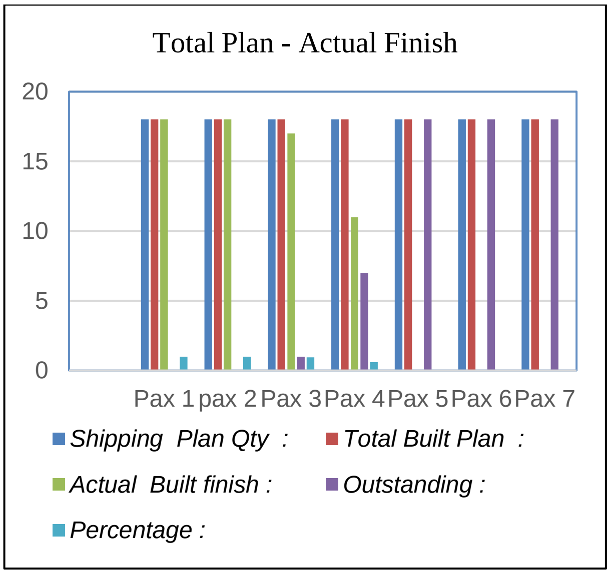

Fig. 2 Difference between planned and actual throughput in PT DI Spirit Aerosystem

Since current traditional production scheduling system in PT DI often leads to production lateness and incapability to deliver production order on time, a better production scheduling system that is capable of generating optimum schedule is required.Genetic Algorithm is one of the alternative methods to solve production scheduling problem, which implements certain search techniques to determine a considerable number of solutions that “stable” and “good enough” for optimization problems(Sivanandam and Deepa, 2008). Based on the identified problem, the objective of this study is using Genetic Algorithm to generate optimum production schedule in PT DI Spirit Aerosystem in such a manner so that minimum tardiness is achieved.

2. MATERIALS AND METHODS

Paksi (2014) quotes Patel (1997) highlighting that improvements at the operational level via better production scheduling will contribute to the manufacturer's success in making timely product delivery to its customers. According to Roshanaei (2012), there is a close relationship between production process problems and product delivery times that requires an efficient, effective and accurate scheduling method to improve customer satisfaction level. This study focuses on developing algorithms to solve job shop scheduling problem in inboard outer fixed leading edge-drive rib 1(IOFLE-DR1) production floor at PT DI Spirit Aerosystem.

Fig. 3 Inboard outer fixed leading edge part of Airbus A380 manufactured by PT DI

Genetic Algorithm was developed by John Holland in 1975 with the aim of solving complex search and optimization problems (Sivanandam and Deepa, 2008). Gen and Cheng (1997) explain that Genetic Algorithms are a powerful optimization method and the most well-known technique in the field of evolutionary computing. Due to the amount and variation of orders from PT DI customers, Genetic Algorithm method is proposed. It is expected that the method will be able to generate an optimal production schedule at the much reduced computation time. The research methodology conducted in this study is explained in the following subsections.

1. Data collection

The study took place from January 2018 through March 2018. Primary and secondary data were collected based on interview with relevant production supervisors and direct observation at PT DI production floor. Data that were collected includes: existing scheduling system, process flow chart, the number of machines, standard processing time, the number of job orders from 2017, job order due date and the number of outstanding job orders during the observation period.

2. Model formulation

The model is developed so that the job allocation for each machine minimizes the tardiness cost.

1. Decision variables
   a. X_{ijk}= The decision to allocate job *j* to machine *i* so that delivery date *k* is fulfilled, X_{ijk} will be equal to 1 if job *j* is allocated to machine *i* for *k* delivery date. Otherwise, X_{ijk} will be equal to 0.
   b. T_j= Tardiness is the difference between completion time of job *j* and due date of job *j*. Tardiness of job *j* has only positive value or equals to 0.
2. The Following symbols are used in the rest of model formulation.
   a. Jo = number of *job* (i = 1,.....,n).
   b. Me = number of machine (k = 1,......m).
   c. $\mathrm{T_i}$ = Tardiness of job number-i.
   d. $\mathrm{id_{jk}}$ = Idle time of machine number-k before job sequence number-j is started.
   e. $\mathrm{P_{ik}}$ = Processing time of job number–i on machine number–k.
   f. $\mathrm{t_{jk}}$ = Waiting time of sequence number–j on machine number–k.
   g. $\mathrm{C_j}$ = Completion time of job sequence number–j.
   h. $\mathrm{S_i}$ = amount of order job–i.
   i. $\mathrm{D_j}$ = Due date of job sequence number–j.
   j. $\mathrm{d_j}$ = Due date of job number–*i*.
3. Objective function

$$MinZ = \Sigma_{j=1}^{n} T_j \qquad (1)$$

4. Constraints
   a. Each job is scheduled once and there is only once on one scheduling horizon.

$$\Sigma_{i=1}^{8} X_{ij} = 1 \qquad \forall j \epsilon j_0 \qquad (2)$$

$$\Sigma_{j=1}^{8} \mathrm{X_{ij}} = 1 \qquad \forall \mathrm{j} \epsilon \mathrm{j_0} \qquad (3)$$

   b. Waiting time for the first job sequence on each machine.

$$t_{1k} = 0 \qquad \forall k \epsilon M \qquad (4)$$

   c. Idle Time for each machine before the first job sequence is executed.

$$id_{1k} = \Sigma_{r=1}^{k-1} \Sigma_{i=1}^{n} P_{ir} X_{1i} \quad (\forall k \epsilon Me = 2, \ldots.m) \qquad (5)$$

   d. A constraint that guarantees that every job follows the same job sequence on a machine.

$$\Sigma_{i=1}^{n} P_{ik} X_{i+1,j} + t_{j+1,k} + id_{j+1,k} = \Sigma_{i=1}^{n} P_{i,k+1} X_{ij} + t_{j,k} + id_{j+1,k+1}$$

$$(\forall j \epsilon Jo - \{1\}) dan (\forall k \epsilon Me - \{1\}) \qquad (6)$$

   e. A constraint that determines the completion time of each job.

$$C_{max} = \Sigma_{j=1}^{n} (\Sigma_{i=1}^{n} P_{im} X_{ij} + id_{jm}) \qquad (7)$$

   f. A constraint that calculates the completion time of all job sequences.

$$\mathrm{C_j} = \Sigma_{j=1}^{n} (\Sigma_{i=1}^{n} \mathrm{P_{im} X_{ij}} + \mathrm{id_{jm}}) \forall \mathrm{j} \epsilon \mathrm{jo} \qquad (8)$$

g. A constraint that determines the due date of a job sequence.

$$D_j = \Sigma_{i=1}^{n} X_{ij} x d_i \forall j \epsilon jo \quad (9)$$

h. Tardiness value of a job.

$$T_j \geq C_j - D_j \quad (10)$$

$$T_j \geq 0 \qquad \forall j \epsilon jo$$

3. Genetic algorithm

This study follows a Genetic Algorithm methodology as suggested by Paksi (2014) and Sivanandam and Deepa (2008).The genetic algorithm procedures in this study are as follows:

1. Identification phase to define the number of jobs, process flow, number of machines, and processing time for each job in each machine.
2. Initiation phase defines a fitness function, constraint and number of initial population.
3. Encoding phase that is a process of using permutation encoding to determine the data ordering problem. Each chromosome/individual of the genetic algorithm represents a permutation of the machine.
4. Decoding phase that is a process of changing chromosomes into solutions, so that the chromosomes can be evaluated for their suitability. At this stage, procedures are carried out to transform chromosomes into Gantt charts.
5. Fitness value is evaluated for each chromosome. This study's goal is to minimize tardiness value or positive difference between completion time and due date. Each chromosome is evaluated using a fitness function as follows:

$$Min\ Z = \Sigma_{j=1}^{n} T_j = \Sigma_{j=1}^{n} CT_j - DD_j \quad (11)$$

CT = Completion Time

DD = Due Date

j = job index(1,2...j)

6. Selection phase uses the roulette wheel method.The roulette wheel method is a method used to calculate the probability of chromosome survival. Some elite chromosomes will be selected as best chromosomes from the population.
7. Construct crossover by using order crossover method.The operator used in this study is a Partially Matched Crossover (PMX). This operator has the principle of exchanging the value of genes that are between two randomly chosen crossover points. If $P_{crossover}$ is the number of chromosomes that experience crossover, P is the population size, and $P_{mutation}$ is the number of individuals who have mutations. The formula used is as follows:

$$P_{mutations} = P - 1 - P_{crossover} . \quad (12)$$

8. Develop mutation process. Calculate fitness value for new offsprings that are produced from crossover and mutation.
9. The condition of the research is achieved when a steady state has been fulfilled. Steady state means that there is no improvement of best fitness value after a number of replications. In this study, the steady states are determined after thirty times, replication has been reached. The best chromosome is then selected based on the best fitness value obtained from those replication.
10. Finishing phase that is a process, making MATLAB coding based on the number of phases described above. Based on the function specified beforehand, the genetic algorithm coding results are verified whether it is in accordance with the expected model.

4. Inboard outer fixed leading edge-drive rib 1 production representation in GA

There are 32 components of IOFLE-DR 1.

The components observed that would be manufactured during this study were Rib Inboard Drive, Outboard Drive Rib, 7 different variations of Plate Spreader, 6 different variations of Cleats, Support Bracket, Bracket, 5 different variations of Electronic Bracket, Stop Pin, 2 variations of Anti Rotation Block, Sleeve Up Stop, Sleeve Down Stop, Bolt Up Stop, Bolt Down Stop, Washer Maintenance Stop, and Bracket Hinge.

There are 39 workstations/machines in the production floor of PT DI Spirit Aerosystem. Each of IOFLE-DR1 components goes through a different process in a specific process flow. Since the process flow is diverse for every IOFLE-DR1 component, the process in PT DI Spirit Aerosystem is categorized as a job shop. In total, there were 150 job orders of various IOFLE-DR 1 components during production year of 2017.Genetic Algorithm method was employed to allocate the resources that minimize the tardiness for all job orders by taking some constraints into account. The following paragraphs explain the representation of the problem as population, chromosome and genes in Genetic Algorithm method.

Population is a collection of chromosomes, while chromosomes are a collection of genes that determine the representation of job order and machining process inboard outer fixed leading edge-drive rib 1 production process. In order to fill out the initial population, random generators were employed to replicate various job orders and machine in PTDI Spirit Aerosystem. The sorting process was done by using a random string number generator as follows:

$$IPOP = Round\,\{Random\,(N_{pop}\,, N_{bits})\} \qquad (13)$$

IPOP = genes consist of round-up string numbers generated from the matrix of N_{pop} *x* N_{bits}.

N_{pop} = *Number of population.*

N_{bits} = Number of genes on each chromosome

A sample of random population generation was used by applying a random number between (0-1). The result is shown in the following table:

Table 1. Random gene representation with jobs

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.933	0.27	0.073	0.36	0.351	0.734	0.726	0.673	0.569	0.435	0.825	0.919	0.311	0.175	0.967	0.693
Sequence	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.088	0.539	0.004	0.315	0.964	0.114	0.581	0.433	0.335	0.35	0.385	0.238	0.837	0.349	0.142	0.781

Then, job sequence was ordered by observing random values of each gene. For example, since gene no.17 had a random value of 0.088, it was placed as the first order in the job sequence. The second smallest random value was gene no.2 to 0.27, so that gene no. 2 was placed on the 2nd job sequence. The process continued until the last sequence was fulfilled. In the end, the order of genes that represent jobs is shown as follows:

Table 2. Jobs order sequence based on the smallest random value

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
job ke -	17	2	9	19	26	7	27	11	31	3	18	4	5	8	13	10
Sequence	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
job ke -	14	6	20	23	28	15	24	22	21	1	30	16	32	12	25	29

In this case, if there are 32 jobs being observed, the initial population would be one big matrix consists of 32 chromosomes each with 32 genes. Then, the initial solution would be done randomly as a set of job permutation in each machine.

3. RESULT AND DISCUSSION.

Genetic Algorithm (GA) program for scheduling system in the IOFLE-DR1 production floor was developed using MATLAB software. The optimum sequence is determined based on a model that is formulated in equation 1 to 10. In these equations, the fitness function is to minimise tardiness. In the GA method, it is necessary to specify the number of population and maximum number of generations. In addition,the value of crossover, mutation rate and steady state replication must also be defined.

1. Data and parameter testing

GA program developed for this study was tested by using historical data in accordance with section 2.1. The following data were used for testing the GA program:

Table 3. Process time data for GA program test

Job	Process time in MachineNumber (minutes)				
	1	2	3	4	5
1	32,5	45,6	26,3	37,8	56,2
2	44,5	43,5	32,4	56,2	33,2
3	23,4	41,5	0	19,6	31,2
4	56,7	78,4	65,8	0	34,2
5	0	45,6	56,7	34,3	14,8

Table 4. Due date data for GA program test

Due Date (Minutes)
234,7
345,5
267,8
235,4
246,8

The parameters used during the GA program test were as follows, population size: 5, percentage of Crossover: 0.6, number of Steady State replication amount: 2

2. Performance test

Using the above mentioned parameters, Encoding phase was started to generate population by randomization number (0-1). Under the principle of the smallest random value precedence, the results of the job sequencing are as follows:

Table 5. Initial population of GA program test

Chromosome	Job Sequence				
1	3	2	1	5	4
2	4	3	1	5	2
3	2	4	5	3	1
4	5	1	3	4	2
5	5	2	3	4	1

The decoding algorithm was used to ensure that there was no replication of the job on the set of chromosomes generated in encoding phase. Then, the fitness value was calculated based on the time of completion of each job. The total tardiness on each chromosome are:

Table 6. Total tardiness for chromosome no.1

Job	Completion Time	Due Date	Tardiness
3	115,7	267,8	0
2	233,2	345,5	0
1	294	234,7	59,3
5	308,8	246,8	74,1
4	381	235,4	146,3
Total *Tardiness*			279,7

Table 7. Total tardiness for chromosome no.2

Job	Completion Time	Due Date	Tardiness
4	235,1	235,4	0
3	266,3	267,8	0
1	342,5	234,7	107,8
5	373,6	246,8	138,9
2	448,2	345,5	213,5
Total *Tardiness*			460,2

Table 8. Total tardiness for chromosome no.3

Job	Completion Time	Due Date	Tardiness
3	209,8	267,8	0
2	279,6	345,5	44,9
1	351,2	234,7	116,5
5	387,2	246,8	152,5
4	450	235,4	215,3
Total *Tardiness*			529,2

Table 9. Total tardiness for chromosome no.4

Job	Completion Time	Due Date	Tardiness
3	151,4	267,8	0
2	230,6	345,5	0
1	261,8	234,7	0
5	311,1	246,8	76,4
4	398,7	235,4	164
Total *Tardiness*			240,4

Table 10. Total tardiness for chromosome no.5

Job	C0mpletion Time	Due Date	Tardiness
3	151,4	267,8	0
2	226	345,5	0
1	257,2	234,7	0
5	309	246,8	74,3
4	395,1	235,4	160,4
Total *Tardiness*			234,7

The next step was the chromosome selection process using a selection algorithm and conducting crossover and mutation processes. The roulette wheel method was employed because it consists of the calculation of total fitness, the proportion of each individual, the cumulative proportion of each individual and a random selection of individuals. Using this method, parents candidate can be selected from the available pool. The following table shows chromosome selection results using Roulette Wheel method.

Table 11. Initial roulette wheel selection process from GA program test

Sequence	Random U(0,1)	Upper limit	Selected chromosome
1	0,12981	0,22264	1
2	0,93542	1	5
3	0,33402	0,47563	2
4	0,53480	0,73467	4

The elitist process was then carried out by selecting the chromosome with the best fitness value in one population to be included in the new parent list. As shown in the initial population, chromosome no. 5 has the best fitness value as it had lowest tardiness value of 234.7. The next step was to do the crossover algorithm process and to calculate the mutation step.The equation 12 was used in those two processes.

At the end of GA program test, a new population was formed from one elite chromosome, 2 chromosomes obtained from the crossover process and 2 other chromosomes obtained from the mutation process. Since, the size of population size was maintained in the same number for 5replications, the population was considered had achieved its Steady State. Putra and Subanar (2011) quotes Ross (1996) saying that replication is required to obtain high accuracy. The purpose of replication of this study is to increase the accuracy of experimental data so that it can be used in the proposed scheduling model. The following table is a new generation of 2nd generation obtained after performing the GA program test.

Table 12. Second generation of population

Chromosome	Job sequence -				
1'	5	2	3	4	1
2'	2	5	3	4	1
3'	2	3	1	5	4
4'	4	5	1	3	2
5'	5	1	2	4	3

The following table shows the results of GA program test calculations from Iteration 1 (early generation) to the last generation (the one with a steady state where the fitness value had been stabilized after 2 replications). Table 13 shows the best fitness value in each generation. Figure 14 and 15 shows the tardiness and fitness value of each generation.

Table 13. Best fitness value for each generation of GA program test

Generation -	Tardiness	Fitness
1	234,7	0,00426076
2	188	0,00531915
3	188	0,00531915
4	188	0,00531915
5	188	0,00531915
6	119,9	0,00834028
7	119,9	0,00834028
8	119,9	0,00834028
9	119,9	0,00834028
10	119,9	0,00834028

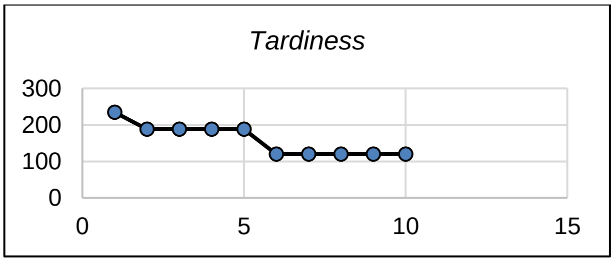

Fig. 4 Tardiness value for each generation from the GA program test

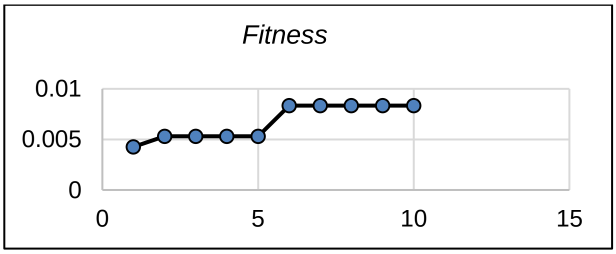

Fig. 5 Tardiness value for each generation from the GA program test

The iteration of the GA program test stopped at the tardiness value of 119.9 and Fitness value for 0.00834028. The solution consists of job sequence 5 - 1 - 3 - 2 - 4 was obtained after 10 iterations, using crossover probability (P_c) = 0.6. Figure 16 shows the Gantt chart of various job sequence from GA program test results

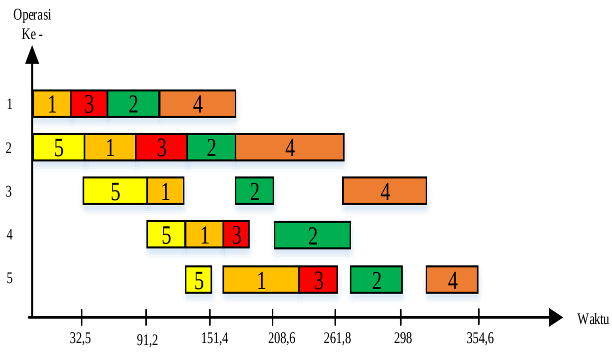

Fig. 6 Gantt chart of job sequence from GA program test

3. IOFLE-DR 1 job scheduling using the proposed GA program

After the GA program test results were validated, GA program was implemented to solve production scheduling problem at PT DI Spirit Aerosystem. In this study several parameters were used to determine the optimal results of IOFLE-DR 1production scheduling. The parameters used in this study were the number of population and the percentage of crossover. GA method in production scheduling was employed to sort 150 job orders into an optimum job sequence that has minimum tardiness. In order to get best parameter for those 150 job orders, correlation test and discriminant analysis were conducted. Correlation analysis concludes that the best parameter setting occurs by a combination of population size 50 with a percentage of crossover 0.6.

Table 14. Parameter test result

% Crossover		**0,6**		**0,95**	
Criteria		***Tardiness* (hour)**	**Computation Time (second)**	***Tardines s* (hour)**	**Computation Time (second)**
N-Population	30	56,766	660,694	1039,713	822,556
	50	17,212	785,337	213,551	1647,776

Based on those parameters, the optimum objective value obtained by the GA program for IOFLE-DR 1 problem is shown in table 15. In this real case problem with 150 job orders, it is observed that the proposed GA program could offer a better result compared to the PT DI Spirit Aerosystem actual schedule. The historical data of previous scheduling using FCFS rule show that PT DI Spirit Aerosystem experienced a delay in total tardiness of 4437.63 hours. Therefore, compared with the solution performed by FCFS rule, the proposed GA produces the best solution. The GA program has the advantage of being able to accommodate the problem of job flexibility, so that the scheduling made is able to solve the problem of positive delay or tardiness. It can be seen from the solution that the job sequencing process was done according to the random value that was in accordance with the characteristics of the object being studied.

Table 15. GA result of IOFLE-DR 1 production scheduling

Seq-	***Job -***	**Seq-**	***Job -***	**Seq -**	***Job-***	**Seq -**	***Job -***	**Seq -**	***Job -***
1	60	31	89	61	43	91	125	121	139
2	96	32	97	62	41	92	87	122	127
3	8	33	142	63	109	93	55	123	94
4	30	34	141	64	76	94	123	124	49
5	19	35	34	65	81	95	61	125	51
6	56	36	35	66	93	96	92	126	82
7	70	37	131	67	5	97	122	127	63
8	58	38	108	68	57	98	50	128	52
9	23	39	148	69	9	99	145	129	111
10	112	40	39	70	3	100	104	130	129
11	128	41	119	71	31	101	48	131	47
12	12	42	144	72	133	102	149	132	132
13	17	43	32	73	42	103	24	133	66
14	14	44	18	74	140	104	99	134	150
15	59	45	72	75	117	105	54	135	75
16	33	46	26	76	29	106	91	136	102
17	134	47	138	77	124	107	115	137	137
18	37	48	15	78	135	108	101	138	147
19	7	49	28	79	20	109	143	139	110
20	16	50	21	80	68	110	27	140	62
21	107	51	67	81	6	111	113	141	53
22	116	52	46	82	130	112	103	142	64
23	22	53	136	83	1	113	80	143	95
24	79	54	118	84	86	114	83	144	11
25	2	55	25	85	84	115	71	145	69
26	13	56	40	86	146	116	77	146	114
27	38	57	10	87	120	117	44	147	100
28	4	58	74	88	90	118	121	148	106
29	98	59	45	89	78	119	73	149	65
30	36	60	126	90	105	120	88	150	85

It also can be seen that the proposed GA method outperforms the FCFS procedure in term of solution quality and calculation time.

4. CONCLUSION.

Based on the result shown in Table 14, the production schedule proposed by this study results in less tardiness compared to the schedules created under FCFS rule. Most of job orders can be completed before the agreed deadline. The other advantage is that the entire schedule can be administered by fewer operators and it takes less than a minute to generate the production schedule for the whole PT DI Spirit Aerosystem job orders. Since the GA method implemented in this study is able to reduce the late delivery in PT DI, it is expected that it will improve PT DI customers' satisfaction.

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