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Optimization of Main Power House Construction Project Scheduling at Sultan Syarif Kasim II Pekanbaru Airport Using Combination of CPM and Genetic Algorithm

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ABSTRACT:*This paper discusses about combination method of CPM and genetic algorithm (GA) for the Main Power House construction project scheduling at Sultan Syarif Kasim II Pekanbaru Airport. This study aims to minimize the average deviation of workers costs per day on the project. By using the CPM method, two schedules are obtained, hereinafter referred as forward CPM and backward CPM. From the results of CPM method calculation, the earliest and latest time limits for the start of each activity in the project are obtained. The time range between these time limits is used to generate the initial population in the computation of the GA method. All stages of GA computation are completed by using MATLAB with various parameter values. The computational results of the CPM-GA combination produce a schedule that is more optimal than the schedule produced by the CPM method. This is indicated by the smaller average deviation of costs per day and higher fitness value than the schedule from the forward CPM and backward CPM.*

KEYWORDS: *scheduling, CPM, genetic algorithm, optimization, CPM-GA*

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I. INTRODUCTION

In a development project, the project owner requires to complete the project properly in minimum time and cost. The minimum time and cost will be obtained by making an effective and efficient schedule by considering the required resources. The most commonly used project scheduling method is the Critical Path Method (CPM).CPM method is a method based on the total duration of the project completion time[1]. Time-based CPM method requires refinement to solve project scheduling optimization problems, because the costs for the project also need to be minimized. Genetic algorithm (GA) is a computational evolution developed to find solutions to the complex optimization problems. The GA method is widely used to solve general optimization problems, such as the mathematical optimization of the value of a function in research[2]and optimization of the application cost of making concrete frames in research[3].

On the research by[4], the CPM method is combined with GA to solve the project scheduling optimization problem to minimize the costs. The results of these research can be used as a reference for combining CPM-GA in time-based and cost-based project scheduling optimization problems generally. Optimization of project scheduling with the combination of CPM-GA was also carried out in [5] in order to optimize time, cost, and time-cost.

Based on previous research, the combination of CPM and GAproduces a more optimal schedule with less cost than using the CPM method alone. In this study, the scheduling optimization of the main power house (MPH) construction project of Sultan Syarif Kasim II PekanbaruAirport that discussed in[6]with a 30% increase in costs. This increasing adjusts the average increasing cost of construction sector workers in Riau, Indonesia from 2016 to 2021.

II. METHODS

This research is divided into four stages, namely:

1. Identify project scheduling optimization problems.

At this stage, the project for which scheduling optimization will be identified. Data regarding activity, duration, predecessor, and hourlycosts of workers per activity are taken from[6]and increased by 30%.

2. Determine the critical path using CPM.

Networks diagram will be established based on project data and the critical path will be determined. Next, the earliestand latest time limits for the start of each activity are used as a limit to generate the initial population in first stage GA method.

3. Determine the most optimal schedule using GA method.

This process will be completed by using MATLAB. The stages of the computation are described as follows:

- The initial population is generated based on the limits obtained from calculations using the CPM method.
- The average deviation of workers cost per day and the fitness value of each individual in the initial population are calculated.
- Individuals with the best fitness values (hereinafter referred to as superior individuals) are selected as parental candidates.
- Superior individuals who pass the roulette wheel selection will be parents and being crossover to form new individuals called offspring.
- Offspring replaces the initial individual with the lowest fitness value.
- The combination of superior individuals and offspring is carried out by allele mutations.
- The population that has allele mutation will be the initial population for the next generation.
- The computations are divided into 2 types, the first is carried out using many generations that have been determined at the beginning and the second is carried out by applying a computational termination condition, the computation will be stopped if the fitness value exceeds the fitness value of the schedule from CPM method.

4. Comparing the results of CPM and CPM-GA scheduling.

At this stage the schedule results from the forward CPM and backward CPM methods are compared with the schedule from the CPM-GA method. The benchmark of the three scheduling results is the fitness value. The most optimal schedule is the schedule that has the highest fitness value.

III. RESULTS AND DISCUSSION

The following are the details of the MPH building construction project at Sultan Syarif Kasim II PekanbaruAirport in Riau, Indonesia.

Table 1 Details of project activities for the construction of the MPH building at Sultan Syarif Kasim II Airport

Activity	Description	Predecessor	Duration
A	Stair work	-	22
B	Mezzanine work in oil warehouse space	A	26
C	Strong electric current	A	54
D	Wall mount work	B	28
E	Rooftop work	C	31
F	Floor and wall coating work	C	49
G	Pump work	C	49
H	Hallway work	D, E, F, G	21
I	Frame, door, window work	H	37
J	Finishing work	H	63
K	Open drainage work	I, J	21
L	Sanitary work	K	8

The details of workers costs per activity with 30% increase is presented in Table 2 as follows.

Table 2 The details of workers costs per activity

Activity	Cost/hour (IDR)
A	581.230
B	1.00.090
C	386,100
D	267,670
E	135,980
F	193.180
G	286.000

H	246.350
I	1,144,000
J	257,400
K	114,400
L	113.360

In this project, it is assumed that workers work 8 hours per day. The scheduling carried out aims to obtain the most optimal schedule to minimize the average deviation of workers cost per day, which is written as follows.

$$B = \frac{1}{T}\sum_{i=1}^{T}|b_i - \bar{b}|,$$

with

B : The average deviation of workers cost per day,
T : Total timeof the project (days),
b_i : Workers cost on day-i,
b : Average workers cost daily.

The fitness function is

$$f = \frac{1}{B+1}$$

First stage of CPM method, it is necessary to develop a network diagram (shown in Fig. 1) to determine the critical path and obtain the results of the forward and backward CPM, as well as the earliest and the latest limits for starting each activity in the project (shown in Table 3 and 4).

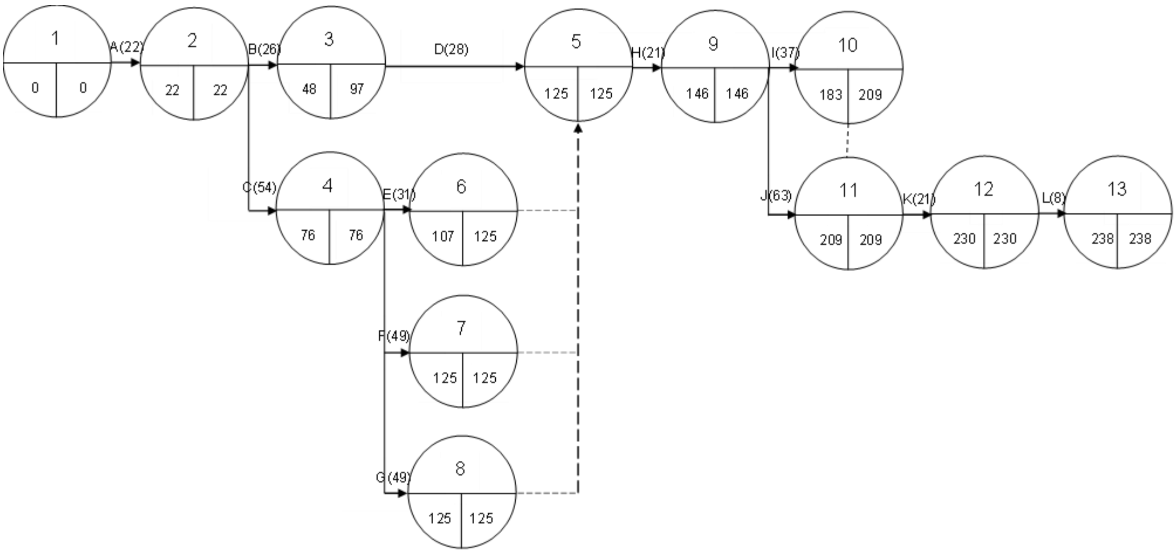

Fig. 1 Network diagram of the project

Table 3 Forward CPM result

Activity	ES	Duration	EF
A	0	22	22
B	22	26	48
C	22	54	76
D	48	28	76
E	76	31	107
F	76	49	125
G	76	49	125
H	125	21	146
I	146	37	183
J	146	63	209
K	209	21	230
L	230	8	238

Table 4 Backward CPM result

Activity	ES	Duration	EF
A	0	22	22
B	22	26	48
C	22	54	76
D	48	28	76
E	76	31	107
F	76	49	125
G	76	49	125
H	125	21	146
I	146	37	183
J	146	63	209
K	209	21	230
L	230	8	238

The average deviation of workers cost per day of the first schedule, which is the schedule from the forward CPM is$3.0285 \times 10^6$and the fitness value is0.3302×10^{-6}. While the backward CPM's average deviation of workers cost per day is3.5690×10^6 with the fitness value 0.2802×10^{-6}.

In addition, based on the results of forward and backward CPM in Table 3 and Table 4, it is also obtained the earliest and the latest time limits for the start of project activities.

Table 5 The earliest and the latest time limits for the start of project activities

Activity	Limit
A	0-0
B	22-71
C	22-22
D	48-97
E	76-94
F	76-76
G	76-76
H	125-125
I	146-172
J	146-146
K	209-209
L	230-230

Optimizing the scheduling of the MPH building construction project at Sultan Syarif Kasim II PekanbaruAirport using GA method is carried out by using the various parameter values, but in the explanation of the stages described below uses the parameter values $N = 16, \alpha_s = 0.3$, and $\alpha_m = 0.2$.

Let the initial population that was generated consisted of $N = 16$ individuals represented in the following table.

Table 6 Initial population

Individual	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
1	1	71	23	69	76	77	77	126	156	147	210	231
2	1	68	23	64	89	77	77	126	158	147	210	231
3	1	67	23	90	87	77	77	126	163	147	210	231
4	1	69	23	90	76	77	77	126	163	147	210	231
5	1	52	23	77	76	77	77	126	149	147	210	231
6	1	22	23	89	85	77	77	126	170	147	210	231
7	1	47	23	61	93	77	77	126	165	147	210	231
8	1	27	23	83	82	77	77	126	158	147	210	231
9	1	64	23	83	89	77	77	126	149	147	210	231
10	1	44	23	84	92	77	77	126	146	147	210	231
11	1	34	23	95	84	77	77	126	150	147	210	231
12	1	37	23	67	80	77	77	126	161	147	210	231
13	1	36	23	56	94	77	77	126	156	147	210	231
14	1	24	23	74	90	77	77	126	157	147	210	231
15	1	22	23	58	88	77	77	126	163	147	210	231
16	1	24	23	53	80	77	77	126	156	147	210	231

.

Individuals 1-16 represent a schedule that satisfies the earliest and the latest time limits in Table 5. $x_1, x_2, \dots, x_{12}$ are genes that exist in one individual chromosome. This gene represents the start time of activity A,B,...,L. As an example, the representation of first individual is the following schedule.

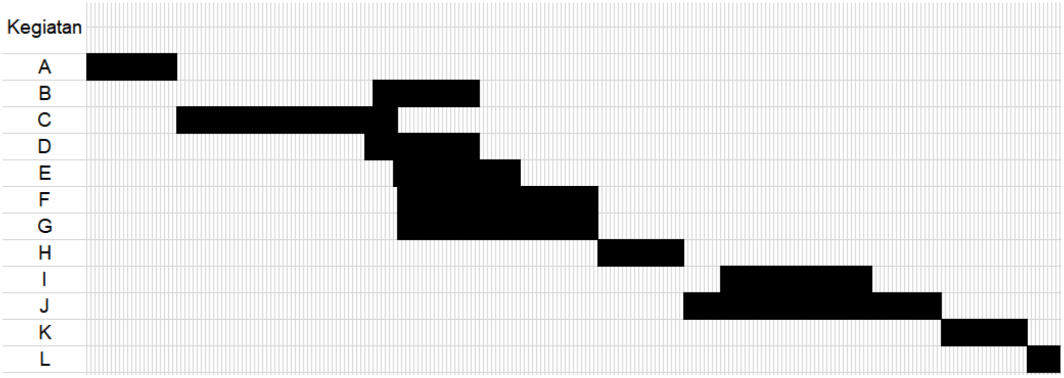

Fig. 2 Representation of first individual from initial population

The order of the best individuals in the initial population based on the fitness value are shown below.

Table 7 The order of individuals based on the fitness value

Individual	**The average deviation of workers cost per day** $(\times 10^6)$	**Fitness value** $(\times 10^{-6})$
16	3.0556	0.3273
15	3.0820	0.3245
13	3.1679	0.3157
12	3.2464	0.3080
14	3.2504	0.3077
7	3.2983	0.3032
10	3.3363	0.2997
11	3.3370	0.2997
8	3.4102	0.2932
6	3.4141	0.2929
5	3.4391	0.2908
9	3.5312	0.2832
3	3.5782	0.2795
2	3.6124	0.2768
4	3.6177	0.2764
1	3.8135	0.2622

These individuals will go through a selection with selection level $\alpha_s = 0.3$. Thus, from 16 individuals in the initial population, 5individuals with the highest fitness values become parents, namely the 16th, 15th, 13th, 12th, and 14th individuals. Next the parents will be crossover each other use the roulette wheel selectionmethods.

Table 8 Expected fitness and selection range for roulette wheel selection

Individual	**Fitness** (10^{-6})	**Expected fitness** (10^{-6})	**Part on the roulette wheel**	**Section range**
16	0.3273	$0.3273/0.31664 \approx 1.0337$	0.2067	$0 - 0.2067$
15	0.3245	$(0.3245)/0.31664 \approx 1.0248$	0.2050	$0.2068 - 0.4117$
13	0.3157	$0.3157/0.31664 \approx 0.9970$	0.1994	$0.4133 - 0.6107$
12	0.3080	$0.3080/0.31664 \approx 0.9729$	0.1946	$0.6108 - 0.8067$
14	0.3077	$0.3077/0.31664 \approx 0.9717$	0.1943	$0.8068 - 1$
	$\sum f = 1.5832$	$\sum Ef = 5.0001$		

Next, random numbers are generated to choose the parental pair. If the number on the selection range, then the individual is selected to be crossover. For example, 4 random numbers are$\{0.3509, 0.1876, 0.6918, 0.9470\}$, then the individual parental pairs are 15 and 16, and 12 and 14. Those individual parental pairs being crossover using arithmetic crossover. 4 offspring will be produced to replace 4 individuals with the lowest fitness value from the initial population. Let the offspring obtained as follows.

Table 9 Offspring from first crossover

Offspring	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
1	1	22	23	58	88	77	77	126	156	147	210	231
2	1	24	23	53	80	77	77	126	163	147	210	231
3	1	37	23	67	80	77	77	126	157	147	210	231
4	1	24	23	74	90	77	77	126	161	147	210	231

The combined initial population and offspring alleles arereplaced with a random number that meets the existing limits in the next stage. The mutation rate used in the computation is $\alpha_m = 0.2$, so the number of alleles on individual chromosome genes in the mutated population is 36.

The GA stages mentioned are one-generation computations, and 16 new individuals are generated. The new population are shown in Table 10 below.

Table 10 New population form one-generation GA computations

Individual	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
1	1	24	23	53	80	77	77	126	156	147	210	231
2	1	22	23	58	81	77	77	126	163	147	210	231
3	1	24	23	74	90	77	77	126	166	147	210	231
4	1	36	23	56	94	77	77	126	156	147	210	231
5	1	37	23	67	80	77	77	126	161	147	210	231
6	1	34	23	95	84	77	77	126	150	147	210	231
7	1	44	23	84	82	77	77	126	146	147	210	231
8	1	27	23	83	77	77	77	126	158	147	210	231
9	1	47	23	94	88	77	77	126	152	147	210	231
10	1	22	23	89	85	77	77	126	170	147	210	231
11	1	52	23	77	77	77	77	126	149	147	210	231
12	1	64	23	83	77	77	77	126	149	147	210	231
13	1	67	23	90	81	77	77	126	163	147	210	231
14	1	69	23	57	76	77	77	126	163	147	210	231
15	1	68	23	64	89	77	77	126	156	147	210	231
16	1	71	23	69	76	77	77	126	156	147	210	231

The computation for generation 2 and so on is completed by using MATLAB, and the final population form 10^{th} generation are shown below.

Table 11 Final population

Individual	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	$B(10^6)$	$f(10^{-6})$
1	1	24	23	50	81	77	77	126	170	147	210	231	3.0330	0.3297
2	1	24	23	50	80	77	77	126	168	147	210	231	3.0330	0.3297
3	1	24	23	50	80	77	77	126	170	147	210	231	3.0330	0.3297
4	1	24	23	50	81	77	77	126	156	147	210	231	3.0330	0.3297
5	1	24	23	50	89	77	77	126	156	147	210	231	3.0330	0.3297
6	1	24	23	50	80	77	77	126	156	147	210	231	3.0330	0.3297
7	1	24	23	50	81	77	77	126	156	147	210	231	3.0330	0.3297
8	1	24	23	50	76	77	77	126	159	147	210	231	3.0637	0.3264
9	1	28	23	53	81	77	77	126	146	147	210	231	3.1374	0.3187
10	1	24	23	66	81	77	77	126	156	147	210	231	3.1769	0.3147
11	1	28	23	76	94	77	77	126	159	147	210	231	3.2236	0.3102
12	1	47	23	74	90	77	77	126	166	147	210	231	3.2504	0.3076
13	1	33	23	97	83	77	77	126	163	147	210	231	3.3325	0.3000
14	1	41	23	50	81	77	77	126	149	147	210	231	3.4362	0.2910
15	1	68	23	50	80	77	77	126	156	147	210	231	3.4909	0.2864
16	1	61	23	58	92	77	77	126	156	147	210	231	3.5173	0.2843

It should be noted that the computational results of each running source code may not be the same, because many random numbers are used in the computation. Furthermore, computations using various values of N, α_s, and $\alpha_m$are being done. Each set of parameter values is computed 5 times and the averages of fitness value are presented below.

Table 12 The Average of fitness value from various parameter values

Parameters Set	**Average of Fitness value** $(\mathbf{10^{-6}})$
$N = 16$ $N_g = 10$ $\alpha_s = 0.3$ $\alpha_m = 0.2$	0.3254
$N = 32$ $N_g = 10$ $\alpha_s = 0.3$ $\alpha_m = 0.2$	0.3292
$N = 16$ $N_g = 30$	0.3283

$\alpha_s = 0.3$ $\alpha_m = 0.2$	
$N = 16$ $N_g = 10$ $\alpha_s = 0.5$ $\alpha_m = 0.2$	0.3256
$N = 16$ $N_g = 10$ $\alpha_s = 0.3$ $\alpha_m = 0.5$	0.3260

Based on Table 12, the effects of population number (N), number of generations (N_g), selection rate (α_s), and mutation rate (α_m) can be known in general. The additional of parameter value canproduce a schedule that has a better fitness value. In the next computation, it will be known in what generation the superior individuals first appeared. The computational results are presented in Table 13 below.

Table 13 Superior individual appears for the first time

Parameters Set	**Superior individual (Fitness value $\mathbf{0.3303 \times 10^{-6}}$) appears for the first time in the -th generation**
$N = 16$ $\alpha_s = 0.3$ $\alpha_m = 0.2$	88
$N = 32$ $\alpha_s = 0.3$ $\alpha_m = 0.2$	8
$N = 16$ $\alpha_s = 0.5$ $\alpha_m = 0.2$	64
$N = 16$ $\alpha_s = 0.3$ $\alpha_m = 0.5$	32

Furthermore, in Table 14, a summary of the average deviation of workers cost per day and fitness values is presented using the CPM method and the CPM-GA method.

Table 14 Summary of the scheduling results using CPM and CPM-GA method

Method	**The average deviation of workers cost per day ($\mathbf{10^6}$)**	**Fitness value ($\mathbf{10^{-6}}$)**
CPM advanced calculation	3.0285	0.3302
CPM countdown	3.5690	0.2802
CPM-GA	3.0277	0.3303

IV. CONCLUSION

CPM-GA combination method produces the most optimal schedule compared to the CPM method, both forward and backward calculations. The forward CPM more effective than the backwards CPM in this case. The CPM-GA combination method produces a schedule that has the smallest average daily deviation of workers cost and the largest fitness value.

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