

SURAT KETERANGAN

Nomor: 929/UNUSA-LPPM/Adm-I/VI/2022

Lembaga Penelitian dan Pengabdian Kepada Masyarakat (LPPM) Universitas Nahdlatul Ulama Surabaya menerangkan telah selesai melakukan pemeriksaan duplikasi dengan membandingkan artikel-artikel lain menggunakan perangkat lunak **Turnitin** pada tanggal 01 Juni 2022.

Judul : Fertilizer Production Planning Optimization Using Particle Swarm Optimization-Genetic Algorithm

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No. Pemeriksaan : 2022.06.10.291

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Submission date: 01-Jun-2022 11:58AM (UTC+0700)

Submission ID: 1848274710

File name: 33._Paper_Jurnal_Fertilizer_Production_Planning.pdf (290.41K)

Word count: 4957

Character count: 25183

Fertilizer Production Planning Optimization Using Particle Swarm Optimization-Genetic Algorithm

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Article history:

Received 1 February 2019
Revised 31 July 2019
Accepted 31 July 2019
Available online 28 October 2019

Keywords:

Constrained Optimization, Genetic Algorithm, Linear Programming, Particle Swarm Optimization, Production Planning

Abstract

Background: The applications of constrained optimization have been developed in many problems. One of them is production planning. Production planning is the important part for controlling the cost spent by the company.

Objective: This research identifies about production planning optimization and algorithm to solve it in approaching. Production planning model is linear programming model with constraints : production, worker, and inventory.

Methods: In this paper, we use heuristic Particle Swarm Optimization-Genetic Algorithm (PSOGA) for solving production planning optimization. PSOGA is the algorithm combining Particle Swarm Optimization (PSO) and mutation operator of Genetic Algorithm (GA) to improve optimal solution resulted by PSO. Three simulations using three different mutation probabilities : 0, 0.01 and 0.7 are applied to PSOGA. Furthermore, some mutation probabilities in PSOGA will be simulated and percent of improvement will be computed.

Results: From the simulations, PSOGA can improve optimal solution of PSO and the position of improvement is also determined by mutation probability. The small mutation probability gives smaller chance to the particle to explore and form new solution so that the position of improvement of small mutation probability is in middle of iteration. The large mutation probability gives larger chance to the particle to explore and form new solution so that the position of improvement of large mutation probability is in early of iteration.

Conclusion: Overall, the simulations show that PSOGA can improve optimal solution resulted by PSO and therefore it can give optimal cost spent by the company for the planning.

I. INTRODUCTION

The applications of constrained optimization have been developed in many problems such as transportation problem [1], production problem [2], supply chain model [3], scheduling optimization [4], and so on. One of constrained optimization is production planning. Production planning is the important part for controlling the cost spent by the company. Production planning which is used in this research is the case study of fertilizer production. In Indonesia having fertile soil, there are some farmers because the demand of food. Because of agriculture production demands, then fertilizer manufacturer produces fertilizer and distributes to farmers. In the production process, there are several costs raised and manufacturer must arrange the planning for revenue and several costs. Therefore this research identifies about production planning optimization and algorithm to solve it in approaching.

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Production planning model is linear programming model with constraints consisting of production, worker, and inventory. Linear programming as optimization problem can be solved by exact method like simplex method and if the solutions are integer then branch and bound and cutting plane method are required [5],[6]. Heuristic methods like Genetic Algorithm (GA) [1], Particle Swarm Optimization (PSO) [7],[8],[9],[10], Artificial Bee Colony (ABC) [11], Firefly Algorithm (FA) [2], Simulated Annealing [12] have applied in many linear programming problem. In constrained optimization using heuristic methods, approaching of new solution must satisfy the given constraints. The satisfaction of constraints can be done by modified new solution [7], penalty technique [9], or goal programming [13].

Genetic Algorithm (GA) was discovered by Goldberg at 1989 [14]. GA works by natural selection process mechanism in chromosomes. Some processes of GA are initialization chromosome population, crossover, mutation, and selection chromosome [15]. Particle Swarm Optimization (PSO) was discovered by Kennedy and Eberhart in 1995. PSO is inspired by the behavior of flocks of birds or fishes with individual is called particle and the population is called a swarm [16].

In previous research, production planning optimization has been done by exact method like simplex method because the model of production planning optimization is linear in objective function and the constraints. Beside of exact method, heuristic methods have been done for approaching optimal solution [2]. However, the heuristic methods in previous research do not introduce the improvement of optimal solution.

In this paper, we use heuristic like Particle Swarm Optimization-Genetic Algorithm (PSOGA) for solving production planning optimization. PSOGA is the algorithm combining PSO and mutation operator of GA to improve optimal solution resulted by PSO. There are many literatures where either PSO or GA can be combined with standard algorithm to improve optimal solution resulted by standard algorithm as : in the researches [7] and [8] explaining about the combining PSO and GA for the transportation problem, in research [13] explaining about the combining Ant Colony Optimization (ACO) and GA for goal programming, in research [3] explaining about the combining PSO and GA for the supply chain model, in research [17] explaining about the combining PSO and Neural Network (NN) for forecasting the data, in research [18] explaining about the combining ACO and GA for the optimization problem.

In this research, data used for production planning optimization are obtained from annual report of one of the fertilizer manufacturer company in Gresik, East Java, Indonesia during 6 periods i.e. 2011, 2012, 2013, 2014, 2015, and 2016. From the data, we can construct mathematical model of production planning with some constraints : production, worker, and inventory. PSO algorithm satisfying constraints production, worker, and inventory can be constructed. The results are minimum cost spent by the company as optimal solution in approaching.

In this proposed method, mutation operator is inserted to PSO algorithm to improve optimal solution. PSOGA is applied by three different mutation probabilities such as 0, 0.01, and 0.7 for comparison. Furthermore, some mutation probabilities in PSOGA will be simulated and percent of improvement will be computed. Improved optimal solutions are obtained so that PSOGA algorithm is smaller and better than PSO algorithm.

II. LITERATURE REVIEW

A. Mathematical Model of Production Planning

Production planning optimization is minimization of cost spent by company as in equation (1) with constraints consisting of production, worker, and inventory as in equation (2), equation (3), equation (4) respectively. Mathematical model of production planning can be constructed as follows [2],[19]:

$$\min \sum_{t=1}^T C_t^p P_t + C_t^w W_t + C_t^h H_t + C_t^l L_t + C_t^i I_t \quad (1)$$

Subject to :

$$P_t \leq n_t W_t, \quad t = 1, 2, \dots, T \quad (2)$$

$$W_t = W_{t-1} + H_t - L_t, \quad t = 1, 2, \dots, T \quad (3)$$

$$I_t = I_{t-1} + P_t - D_t, \quad t = 1, 2, \dots, T \quad (4)$$

$$P_t, W_t, H_t, L_t, I_t \geq 0, \quad t = 1, 2, \dots, T \quad (5)$$

with T is the planning time, D_t is the number of units demanded in time t , n_t is the number of units produced by a worker in time t , C_t^P is the production cost per unit in time t , C_t^W is the worker cost in time t , C_t^H is the hired worker cost in time t , C_t^L is the fired worker cost in time t , C_t^I is the inventory holding cost in time t , P_t is the number of units produced in time t , W_t is the number of workers available in time t , H_t is the number of hired workers in time t , L_t is the number of fired workers in time t , I_t is the number of inventory in time t .

In the equation (2), the number of units produced limits the number of units produced by current workers. In the equation (3), the number of current workers is the function of previous workers, hired worker, and fired worker. In the equation (4), the number of current inventory is the function previous period inventory, the number of units produced, and the current demand. In the equation (5), the solutions must be positive and integer number.

B. Particle Swarm Optimization (PSO)

PSO was the optimization method discovered by Kennedy and Eberhart in 1995. PSO mimics the behavior of flocks of birds or fishes with individual is called particle and the population is called swarm. Each particle has initial position and velocity. When particle finds the source of food, the others will follow them based on particle velocity [20].

Based on behavior of flocks of birds or fishes, then standard PSO algorithm is given as in Fig. 1.

```

Initialize particle position  $x_{ij}^k(0)$ ,  $k = 1, 2, \dots, \text{maxswarm}$ 
Initialize particle velocity  $v_{ij}^k(0)$ ,  $k = 1, 2, \dots, \text{maxswarm}$ 
Set local best particle  $p_{ij}^k = x_{ij}^k(0)$ ,  $k = 1, 2, \dots, \text{maxswarm}$ 
Set global best particle  $g_{ij} = \arg \min_p (f(p_{ij}^k), k = 1, 2, \dots, \text{maxswarm})$ 

Update particle along time  $t$ .
for  $t = 0 : \text{maxt}$ 
  for  $k = 1 : \text{maxswarm}$ 
    Compute the particle velocity  $v_{ij}^k(t+1)$  with  $r_1$  and  $r_2$  are random number between (0,1), inertia weight  $\omega = 1$ , and  $c_1 = c_2 = 2$ 

$$v_{ij}^k(t+1) = \omega v_{ij}^k(t) + c_1 r_1 (p_{ij}^k - x_{ij}^k(t)) + c_2 r_2 (g_{ij} - x_{ij}^k(t))$$

    Update the particle position  $x_{ij}^k(t+1)$ 

$$x_{ij}^k(t+1) = x_{ij}^k(t) + v_{ij}^k(t+1)$$

    Compute the fitness of particle  $f(x_{ij}^k(t+1))$ 
    Update local best particle  $p_{ij}^k$ 

$$p_{ij}^k = \arg \min_x (f(x_{ij}^k(0)), f(x_{ij}^k(1)), \dots, f(x_{ij}^k(t)), f(x_{ij}^k(t+1)))$$

  End
  Update global best particle  $g_{ij}$ 

$$g_{ij} = \arg \min_p (f(p_{ij}^k), k = 1, 2, \dots, \text{maxswarm})$$

End

```

Fig. 1 Pseudocode of Standard PSO Algorithm

C. Particle Swarm Optimization-Genetic Algorithm (PSOGA)

Particle Swarm Optimization-Genetic Algorithm (PSOGA) is the algorithm combining Particle Swarm Optimization (PSO) with mutation operator of Genetic Algorithm (GA) for improving optimal solution [8]. Mutation operator of GA is inserted to PSO algorithm to produce new optimal solution based on mutation probability. Mutation process occurs when probability is less than mutation probability p_m . After mutation process is implemented in the current population, it will result new population for next iteration.

III. METHODS

A. Initialization Population

For the production planning problem, the particle as the decision variable is the matrix where the elements are : P_t is the number of units produced in time t , W_t is the number of workers available in time t , H_t is the number of hired workers in time t , L_t is the number of fired workers in time t , I_t is the number of inventory in time t . The design of decision variable can be seen in equation (6).

$$X^k = (P, W, H, L, I) = \begin{bmatrix} P_1 & P_2 & \dots & P_T \\ W_1 & W_2 & \dots & W_T \\ H_1 & H_2 & \dots & H_T \\ L_1 & L_2 & \dots & L_T \\ I_1 & I_2 & \dots & I_T \end{bmatrix} \quad (6)$$

In the first step of PSOGA, we need to initialize the population of particle. The initialization of particle must satisfy constraints (2) - (5). In order to satisfy constraints, the initialization can be designed as in Fig. 2.

```

initialization(max H, max L, maxswarm)
for k = 1 : maxswarm
  Generate  $H_t^k(0) \sim U(0, \max H)$  and  $L_t^k(0) \sim U(0, \max L)$ ,  $t = 1, 2, \dots, T$  uniformly distributed
  Set  $W_0^k(0)$ 
  for t = 1 : T
     $W_t^k(0) = W_{t-1}^k(0) + H_t^k(0) - L_t^k(0)$ 
  end
  for t = 1 : T
     $P_t^k(0) \leq n_t W_t^k(0)$ 
  end
  Set  $I_0^k(0)$ 
  for t = 1 : T
     $I_t^k(0) = I_{t-1}^k(0) + P_t^k(0) - D_t$ 
  end
end

```

Fig. 2 The Initialization of PSO Satisfying Constraints

B. Update the Particle

We need to modify update the particle and velocity on PSO so that new particle can satisfy constraints in (2) – (5). The modification of update particle and velocity can be designed as in Fig. 3.

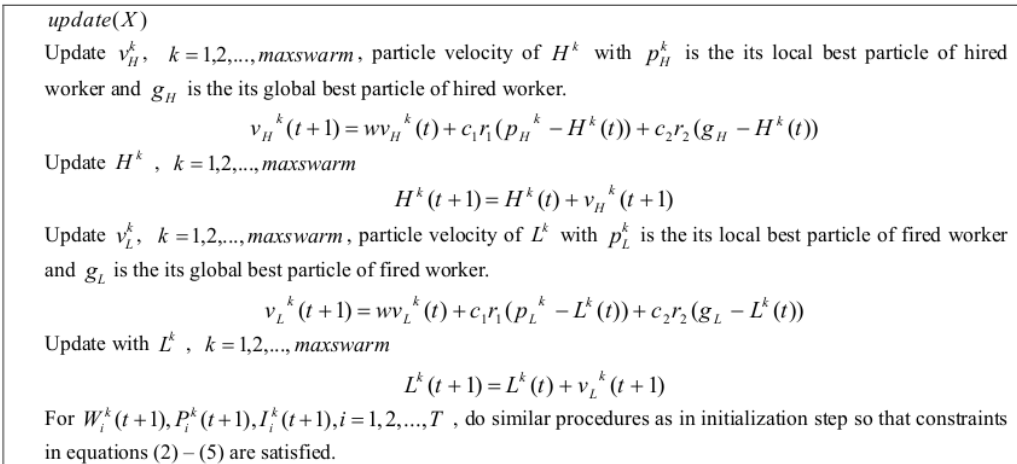


Fig. 3 The Update Particle of PSO Satisfying Constraints

C. Mutation Operator

Mutation operator is one of the operator used in Genetic Algorithm (GA). In GA, mutation process changes some unit of origin chromosome to create new chromosome depends on mutation probability p_m [15]. Mutation operator can improve optimal solution which is resulted by PSO because mutation operator can find the new solution. Mutation operator must be designed to satisfy constraints (2) – (5). The algorithm of mutation operator can be constructed as in Fig. 4.

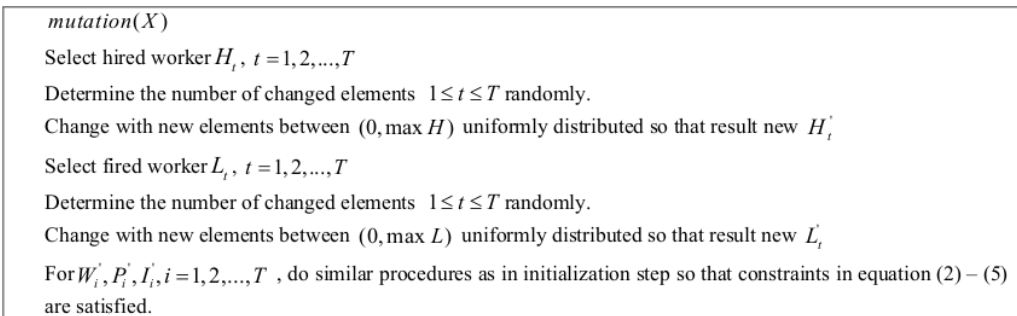


Fig. 4 The Mutation Particle Satisfying Constraints

D. Overall Algorithm

This method introduces the improvement of standard PSO or other heuristics in previous research. In addition, mutation operator as in Fig. 4 is inserted to PSO algorithm for improving optimal solution. This algorithm is called PSOGA as in Fig. 5. Mutation operator is inserted after the particle are updated.

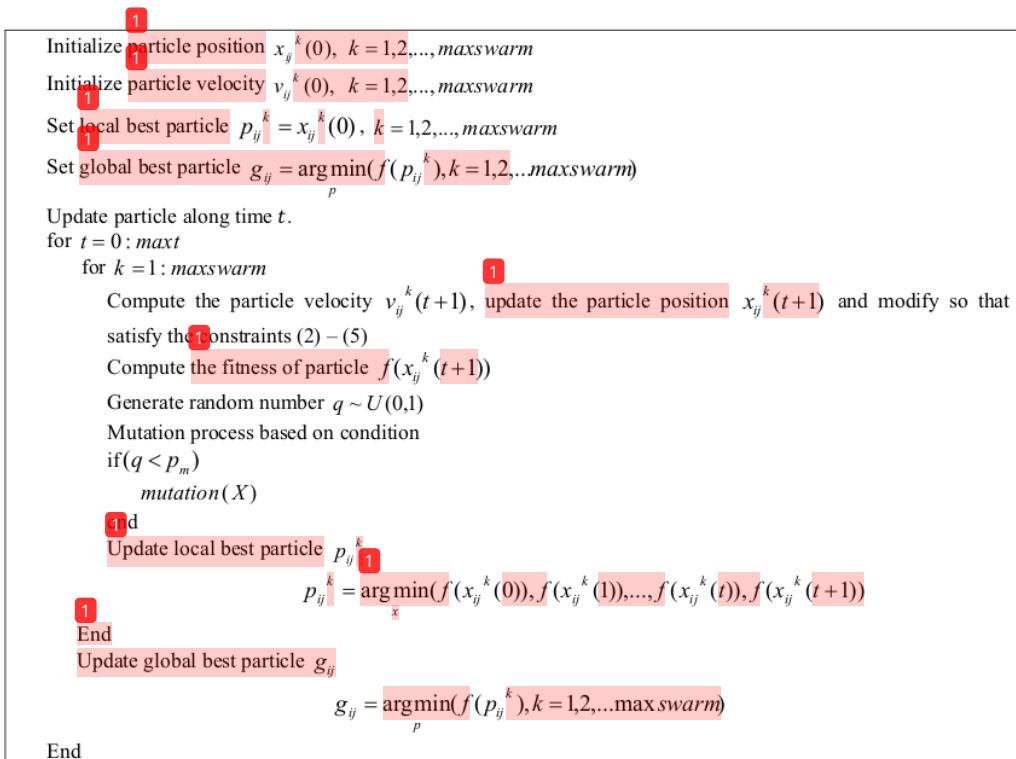


Fig. 5 Pseudocode of PSOGA Algorithm

IV. RESULTS

The method used in this research can be seen as diagram in Fig. 6 :

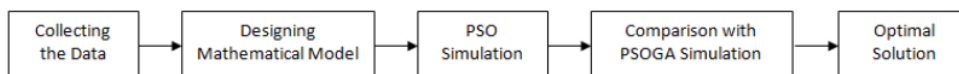


Fig. 6 The Diagram of PSOGA Method

Data used in the simulations are obtained from one of the fertilizer manufacturer company in Gresik, East Java, Indonesia during 6 periods i.e. 2011, 2012, 2013, 2014, 2015, and 2016. From the data, we can make fertilizer production planning optimization. Table 1 shows cost per unit in each year which consists : production cost per unit C_t^p , worker cost C_t^w , hired worker cost C_t^H , fired worker cost C_t^f , and inventory holding cost C_t^I , for each year $t = 2011, 2012, 2013, 2014, 2015, 2016$. Table 2 shows the number of units demanded for each period D_t and the number of units produced by a worker for each period n_t for each year $t = 2011, 2012, 2013, 2014, 2015, 2016$

TABLE 1
VALUE OF COST PER UNIT (IN MILLION RUPIAHS)

	2011	2012	2013	2014	2015	2016
C_t^P	4.00	4.54	5.17	5.33	5.71	5.33
C_t^W	7	7	7	7	7	7
C_t^H	4	4	4	4	4	4
C_t^L	2	2	2	2	2	2
C_t^I	2.46	3.83	4.34	4.03	4.63	4.26

TABLE 2
THE NUMBER OF UNITS DEMANDED (IN TONS) AND THE NUMBER OF UNITS PRODUCED BY A WORKER (IN TONS/WORKER)

	2011	2012	2013	2014	2015	2016
D_t	4328630	5008571	5409669	5375396	5546783	5357118
n_t	1060	1271	1249	1266	1285	1292

From the data obtained, we can construct mathematical model of production planning with minimization of cost spent by company as in equation (1) and some constraints consisting of production as in equation (2), worker as in equation (3), and inventory as in equation (4). After the data are used in mathematical model of production planning optimization, PSO algorithm satisfying constraints (2), (3), (4) and (5) can be constructed as Fig. 1 with initialization particle as in Fig. 2 and update particle as in Fig. 3. The simulations are applied by Matlab. The results are minimum cost spent by the company in equation (1) as optimal solution in approaching.

PSOGA is applied by three different mutation probabilities : 0, 0.01, and 0.7 for comparison. Furthermore, some mutation probabilities in PSOGA will be simulated and percent of improvement will be computed. The simulations are also applied by Matlab. The results are minimum cost spent by the company in equation (1) as optimal solution in approaching and its improvement of PSO.

A. Simulation with Mutation Probability is 0

Fig. 7 shows the simulation of PSOGA on production planning optimization with mutation probability is 0. In early time, the particle positions are chosen randomly. In the optimization process, position and velocity particle are updated so that fitness will decrease and converge. From the simulation, PSOGA simulation shows similar plot with PSO simulation and there is no improvement along iteration so that PSOGA with no mutation probability is similar to PSO with objective value in equation (1) as fitness is 214698345 million rupiahs.

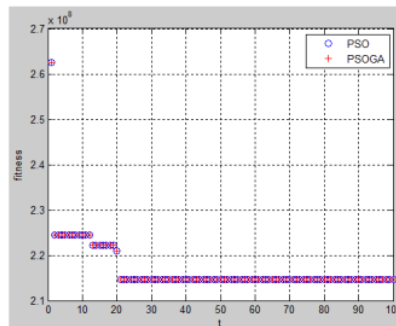


Fig. 7 Optimization Result by PSOGA with Mutation Probability is 0

Decision variable as optimal solution in approaching of PSOGA with mutation probability is 0 can be seen in Table 3 where in the elements are H_t is the number of hired workers in time t , L_t is the number of fired workers in time t , P_t is the number of units produced in time t , W_t is the number of workers available in time t , I_t is the number of inventory in time t .

TABLE 3
OPTIMAL SOLUTION BY PSOGA WITH MUTATION PROBABILITY IS 0

	2011	2012	2013	2014	2015	2016
H_t	128	129	218	368	118	105
L_t	296	224	234	274	236	210
W_t	3179	3084	3068	3162	3044	2939
P_t	2712106	3298229	3206010	3267430	3178487	3384140
I_t	10588643	8878301	6674642	4566676	2198380	225402

B. Simulation with Mutation Probability is 0.01

Fig. 8 shows the simulation of PSOGA on production planning optimization with mutation probability is 0.01. In early time, the particle positions are chosen randomly. In the optimization process, position and velocity particle are updated so that fitness will decrease and converge. From the simulation, because the mutation probability is relative small, there is improvement in the middle of iteration so that PSOGA gives smaller and better optimal solution than PSO with objective value in equation (1) as fitness is 210540703 million rupiahs.

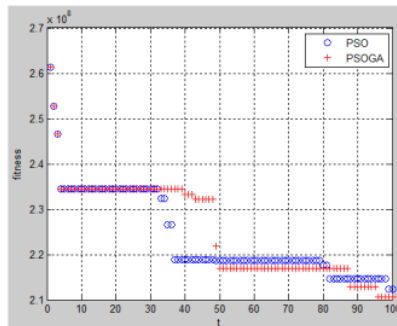


Fig. 8 Optimization Result by PSOGA with Mutation Probability is 0.01

Decision variable as optimal solution in a **4** reaching of PSOGA with mutation probability is 0.01 can be seen in Table 4 where in the elements are H_t is the number of hired workers in time t , L_t is the number of fired workers in time t , P_t is the number of units produced in time t , W_t is the number of workers available in time t , I_t is the number of inventory in time t .

TABLE 4
OPTIMAL SOLUTION BY PSOGA WITH MUTATION PROBABILITY IS 0.01

	2011	2012	2013	2014	2015	2016
H_t	132	144	123	192	227	104
L_t	298	277	210	241	292	206
W_t	3181	3048	2961	2912	2847	2745
P_t	2774050	3150904	3012529	3267123	3438735	3223916
I_t	10650587	8792920	6395780	4287507	2179459	46257

C. Simulation with Mutation Probability is 0.7

Fig. 9 shows the simulation of PSOGA on production planning optimization with mutation probability is 0.7. In early time, the particle positions are chosen randomly. In the optimization process, position and velocity particle are updated so that fitness will decrease and converge. From the simulation, because the mutation probability is relative

large, there is improvement in the early of iteration so that PSOGA gives smaller and better optimal solution than PSO with objective value in equation (1) as fitness is 210871781 million rupiahs.

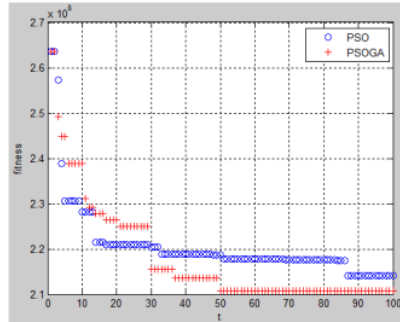


Fig. 9 Optimization Result by PSOGA with Mutation Probability is 0.7

Decision variable as optimal solution in approaching of PSOGA with mutation probability is 0.7 can be seen in Table 5 where in the elements are H_t is the number of hired workers in time t , L_t is the number of fired workers in time t , P_t is the number of units produced in time t , W_t is the number of workers available in time t , I_t is the number of inventory in time t .

TABLE 5
OPTIMAL SOLUTION BY PSOGA WITH MUTATION PROBABILITY IS 0.7

	2011	2012	2013	2014	2015	2016
H_t	119	158	104	174	248	328
L_t	251	244	260	228	235	121
W_t	3215	3129	2973	2919	2932	3139
P_t	2726575	3222682	3160912	3146478	3075325	3638297
I_t	10603112	8817223	6568466	4339548	1868090	149269

D. Simulations with Some Mutation Probabilities

The comparison between PSO and PSOGA with some mutation probabilities can be seen in Table 6. The position of improvement of small mutation probability ($0.01 \leq p_m \leq 0.09$) is in middle of iteration. The position of improvement of large mutation probability ($0.1 \leq p_m \leq 0.9$) is in early of iteration (iteration = 2). Mutation operator can improve optimal solution resulted by PSO to become smaller because mutation operator can explore the new solution. The small mutation probability gives smaller chance to the particle to explore and form new solution so that the position of improvement of small mutation probability is in middle of iteration. The large mutation probability gives larger chance to the particle to explore and form new solution so that the position of improvement of large mutation probability is in early of iteration. From the Table 6, we can see that PSOGA can improve optimal solution resulted by PSO with smaller and better value with percent improvement as in (7):

$$\text{percent improvement} = \frac{(\text{best fitness PSO} - \text{best fitness PSOGA})}{\text{best fitness PSO}} \times 100\% \quad (7)$$

with the average of overall percent improvement is 0.9738 percent.

TABLE 6
COMPARISON PSO AND PSOGA WITH SOME MUTATION PROBABILITIES

No	Mutation Probability	Position of Improvement (of 100 iterations)	Time Computation (second)	PSO Best Fitness ($\times 10^6$)	PSOGA Best Fitness ($\times 10^6$)	% Improvement
1	0.01	36	2.4382	2.1484	2.1352	0.6144
2	0.02	27	2.1673	2.1341	2.1105	1.1059
3	0.03	39	2.1483	2.1274	2.0900	1.7580
4	0.04	21	2.2162	2.1362	2.1281	0.3792
5	0.05	12	2.2381	2.1345	2.1129	1.0120
6	0.06	8	2.2517	2.1504	2.1432	0.3348
7	0.07	8	2.5633	2.1457	2.1052	1.8875
8	0.08	7	2.3067	2.1617	2.1300	1.4664
9	0.09	4	2.6065	2.1291	2.1072	1.0286
10	0.1	6	2.2081	2.1632	2.1558	0.3421
11	0.2	3	2.2912	2.1323	2.0849	2.2230
12	0.3	2	2.6372	2.1624	2.1526	0.4532
13	0.4	2	2.7390	2.1626	2.1439	0.8647
14	0.5	2	2.8554	2.1408	2.1371	0.1728
15	0.6	2	2.4766	2.1855	2.1783	0.3294
16	0.7	2	2.7459	2.1456	2.1387	0.3216
17	0.8	2	2.6268	2.202	2.1871	0.6767
18	0.9	2	2.6740	2.2203	2.1635	2.5582
Average			2.4550	2.154567	2.133567	0.9738

V. DISCUSSION

Three simulations using three different mutation probabilities are applied to PSOGA. From the first simulation with mutation probability is 0, PSOGA simulation shows similar plot with PSO simulation and there is no improvement along iteration so that PSOGA with no mutation probability is similar to PSO. From the second simulation with mutation probability is 0.01, because the mutation probability is relative small, there is improvement in the middle of iteration so that PSOGA gives smaller and better optimal solution than PSO. From the third simulation with mutation probability is 0.7, because the mutation probability is relative large, there is improvement in the early of iteration so that PSOGA gives smaller and better optimal solution than PSO. The small mutation probability gives smaller chance to the particle to explore and form new solution so that the position of improvement of small mutation probability is in middle of iteration. The large mutation probability gives larger chance to the particle to explore and form new solution so that the position of improvement of large mutation probability is in early of iteration.

VI. CONCLUSIONS

Production planning optimization is one of constrained optimization with constraint production, worker, and inventory. Heuristic method like PSO has been applied in approaching optimal solution by modifying the particle position and particle velocity so that particle can satisfy the constraints. In this research, PSO is combined by mutation operator of GA. From the simulations, PSOGA can improve optimal solution of PSO and the position of improvement is also determined by mutation probability. The developments of this research are the products produced not only one product but also they can be multiple products so that new optimization model can be researched.

ACKNOWLEDGMENTS

High appreciation to the Ministry of Research, Technology and High Education (Kemenristekdikti), Republic of Indonesia for the Penelitian Dosen Pemula fund for the research conducted in the year 2019.

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