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# Sequential use of blocplan, solver, and particle swarm optimization (PSO) to optimize the double row facility layout

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**Abstract:**

Facility layout optimization is used to increase company productivity by minimizing waste on transportation, movement, and waiting time. It was mentioned in several previous studies that optimal facility layout can reduce production costs by up to 40%. Because of this importance, many previous researchers have carried out research in the field of Facility Layout. The differences between each Facility Layout research are in the characteristics and criteria being analyzed and the optimization method used. The several approaches used to optimize the layout are constructed algorithm, exact algorithm, and metaheuristic. These three methods have their respective purposes and to the best of our knowledge have not been used sequentially. So, this study aims to find the best layout for the double-row facility problem with aisle width consideration using three sequential methods. There are BLOCPLAN for the constructed algorithm, solver for the exact algorithm, and Particle Swarm Optimization (PSO) for the metaheuristic. The result shows that the use of BLOCPLAN gives a better result of Total Material Handling Cost (TMHC) in PSO. For more machines, PSO has better results than Gurobi Optimization.

**Key words:**

Facility Layout, TMHC, BLOCPLAN, Solver Gurobi, PSO, double row.

## 1. Introduction

The layout is an effective way to reduce costs and make the productivity and workflow increased on the production line (Dharsono, 2016). Layout planning is a central part of the production process in the company (Klar et al., 2022) so when this problem is resolved, the company can maximize its entire production process (Maghfiroh, 2021). A well-designed layout can help companies reduce some waste, such as transportation, motion, and waiting (Rifai et al., 2022). When the material flow is improved through the layout, it can automatically reduce production costs by up to 40% (Matthew P. Stephens, 2013).

In planning the facity layout several conditions in the production line area need to be considered such as the production area, number of facilities, facility dimensions, and material handling configurations (Pérez-Gosende et al., 2023). Meanwhile, Hosseini-Nasab et al. (2018) formulated several facility layout classification criteria, namely problem types, planning approaches and phases, production facility characteristics, and material handling configurations. In addition to the condition of the production area, in optimizing the layout of the facility, it is necessary to pay attention to the mathematical model used. The combination of area conditions and mathematical models is novel to the previous facility layout research.

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Research on improving or optimizing facility layout planning varies widely and is growing quite rapidly. The differences in facility layout problems are in the combination of problems based on the classification criteria and the optimization method approach used along with the limitations of the problem. Facility layout planning is an NP-Hard problem (Non-Polynomial Hard Problem) because there is no algorithmic method that can provide the most optimal results (Grobelny & Rafal Michalski, 2017). Thus, various algorithms and their improvements are proposed in the problem of facility layout planning.

Several facility layout optimization approaches have been used in previous studies. There are 3 types of facility layout optimization approaches, namely constructed algorithm, mathematical programming or exact method, and metaheuristic. Constructed Algorithms used based on literature studies are Systematic Layout Planning (SLP) and Distance Measurement. Naim et al. (2020) and Khariwal et al. (2020) used SLP in case studies at Precast Concrete or Prefabricated Concrete companies. Kovács & Kot (2017) and Putri & Dona (2019) used distance measurement in layout design to find the minimum distance for material movement. This constructed algorithm approach can be used for optimizing facility layout on certain problems (case study) and can only provide several corrective solutions.

Su & Nishimura (2022), Erik & Kuvvetli (2021), Pourvaziri et al. (2021), and Brunoro Ahumada et al. (2018) used Linear Programming as an exact method to optimize static product layout facility problem. Whereas, metaheuristic algorithm is a lot to use in facility problems that have many data sets and provide better computing time results.

In this study, three optimization methods will be used sequentially to optimize the double-row facility layout problem. The constructed algorithm used in this study is BLOCPLAN, the exact method used is a solver using Gurobi Optimizer, and the metaheuristic used is Particle Swarm Optimization (PSO).

## 2. Research Contribution

The contribution of this study is the use of three approaches in optimizing facility layout, namely constructed algorithm, exact method, and metaheuristic. BLOCPLAN is one of the constructed algorithms that has been widely used in facility layouts. The output of the BLOCPLAN algorithm is the layout alternatives based on the iteration and the value of the adjective score, R-Square, and REL Distance. These values are being used as the decision to choose the best layout. The solver as an exact approach needs to be used to get the optimal value. Particle Swarm Optimization (PSO) as a metaheuristic method is used to obtain near-optimal values with faster computation time than the exact method.

## 3. Methodology

As an never used sequential methods in facility layout, researchers have to make the framework of the way to think and work (Figure 1).

The first step in this research is to find the best layout using the BLOCPLAN algorithm and it will be used as an input parameter in exact and metaheuristic algorithm. It will be used GUROBI as an exact algorithm and Particle Swarm Optimization (PSO) as an metaheuristic algorithm. The output of the Gurobi and PSO is the optimal and near-optimal layout positions in rows 1 and row 2. From these results, the Total Material Handling Cost (TMHC) and computing time will be compared so that the conclusion is obtained.

### 3.1. BLOCPLAN

In this study, BLOCPLAN 90 was used. BLOCPLAN has been used by Sitepu et al. (2020), Lufika et al. (2021), and Siregar et al. (2020) to improve the production facility design. The input of the BLOCPLAN algorithm is the Activity Relationship Chart (ARC), which is the design of proximity between facilities based on qualitative criteria (Putri & Dona, 2019).

- Step 1: Input the workstation specification (name and width)
- Step 2: Input the Code of Activity Relationship Chart (ARC) (A, E, I, O, U, X)
- Step 3: Determine the fixed location of the workstation (optional)
- Step 4: Set and run the iteration of the Automatic Layout
- Step 5: Analyze the adjective score, R Score, and REL Dist Score
- Step 6: Choose the best layout depending on the analysis

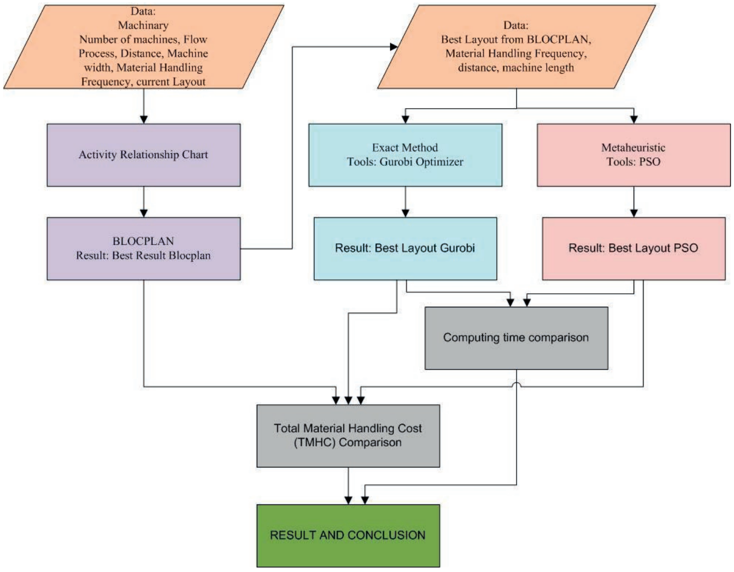



**Figure 1.** Framework for using Constructed Algorithm, Solver, and Meteheurictic.

### 3.2. Mathematical Model

The mathematical model in this study is used to design the program in Solver Gurobi and PSO. It has several assumptions: (i) clearance between machines is included in the length of the machine (ii) the loading/unloading point is located in the center of the machine (iii) material handling configuration of the facility layout is a double row

Here is some consideration of the index set, parameters, dependent variables, decision variables, and objective function used in this research.

*Index* set:
$i, j$: facility indicator ($i,j$ = 1,2,3,..n)
$p$: facility location indicator (p=1,2,3,.. n)
$t$: layout stage
$T$: total number of layout stage

*Paramters*:
$n$: number of facilities
L: length of the plant (meter)
$l_i$: the length of facility i (meter)
$f_{ij}$: the handling frequency between facility $i$ to $j$ in the L stage
$g$: aisle width (meter)

*Dependent Variables:*
$d_{ij}$: distance between the center of facility $i$ and $j$
$x_i$: abscissa location of the center of the machine $I$ (loading/unloading point from facility $i$)

*Decision Variables:*
$a_{ij}$: binary variables to avoid overlapping the facility in the same row. 1 if the facility is placed to the right of machine $i$, 0 otherwise
$r_{ij}$: binary variables to indicate the row of the facility. 1 if the facility i and j in the same row, 0 otherwise.

*Objective Function:*
The objective function of this research is to minimize the total material handling cost.

F = min (TMHC)

$$TMHC = \sum_{i=1}^{n-1} \sum_{j=i+i}^{n} f_{ij} \times d_{ij} \quad (1)$$

*TMHC* is obtained from the multiplication between the distance and frequency of material movement from the machine $i$ to machine $j$.

And here are several constraints that are used in this study.

a. Location

Ensuring that the facility is only placed in one location and only one facility is allowed in one location. It can not be more than one facilities are located in one location.

$$\sum_{i=1}^{n} X_{ip}^{t} = 1, p=1,2,3,\dots n \quad (2)$$

$$\sum_{p=1}^{n} X_{ip}^{t} = 1, i=1,2,3,\ldots n \quad (3)$$

b. Distance between machine

Determining the distance between facilities $i$, $j$, and abscissa constant value

$$d_{ij} \geq x_i - x_j + g(1-r_{ij}) \quad (4)$$

$$d_{ji} \geq x_j - x_i + g(1-r_{ij}) \quad (5)$$

c. Prevent the overlap

Ensuring there is no overlap of facilities when placed on the same row.

$$x_j + \frac{l_i + l_j}{2} \leq x_i + L(1+a_{ij}-r_{ij}) \quad (6)$$

$$x_i + \frac{l_i + l_j}{2} \leq x_j + L(2-a_{ij}-r_{ij}) \quad (7)$$

d. Determine the lower bound of the distance

$$d_{ij} \geq \left(\frac{l_i + l_j}{2}\right) r_{ij} + g(1-r_{ij}) \quad (8)$$

e. Ensuring the consistency of inequality in the distance variable

$$d_{ij} - d_{ik} - d_{jk} \leq 0 \quad (9)$$

$$-d_{ij} + d_{ik} - d_{jk} \leq 0 \quad (10)$$

$$-d_{ij} - d_{ik} + d_{jk} \leq 0 \quad (11)$$

f. Ensuring the consistency of inequality in the variable indicating the row of the facility (row 1 or 2)

$$r_{ij} + r_{ik} + r_{jk} \geq 1 \quad (12)$$

$$-r_{ij} + r_{ik} + r_{jk} \leq 1 \quad (13)$$

$$r_{ij} - r_{ik} + r_{jk} \leq 1 \quad (14)$$

$$r_{ij} + r_{ik} - r_{jk} \leq 1 \quad (15)$$

g. Provide a value limit on the abscissa variable

$$x_i \leq L - \frac{l_i}{2} \quad (16)$$

h. The relationship between the variables $r$ and $y$

$$y = \sum_{j=1}^{n} rij \ \forall\ i = 1,2,3,\ldots n \quad (17)$$

i. Only one row for each facility

$$\sum_{t=1}^{T} y = 1 \ \forall\ i = 1,2,3,\ldots n \quad (18)$$

### 3.3. Solver

Solver is a tool to find an optimal solution to some problems. The limitation of this tool is the number of data sets. The more data set are resolved to make the longer computation time. The solver used to solve the double-row layout problem in this study is Gurobi Optimizer 10.0.1.

### 3.4. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a proven method to find near-optimal solutions to Facility Layout Problems. Some previous research from Li et al. (2018), Samarghandi et al. (2010) and Revathi & Malathi (2017) used PSO to solve the single-row facility layout problem. PSO was also used by Cravo et al. (2021) and Guan et al. (2020) to solve the double-row layout problem. Another study in facility layout with PSO was driven by C. Guan et al. (2019) who solve the multi-row facility layout and unequal size dynamic facility layout. From that research, it can be concluded that facility layout is an NP-Hard Problem and can be solved by metaheuristic methods including Particle Swarm Optimization (PSO). The deference parameter of this research is an aisle width consideration. Some previous research is not determining the aisle width. It is assumed that the aisle is negligible.

## 4. Result

The optimization of double row facility layout in this study is based on the manufacturing company in Indonesia. This company produces transportation equipment. It has 7 machines located in two rows separated by an aisle ($g$).

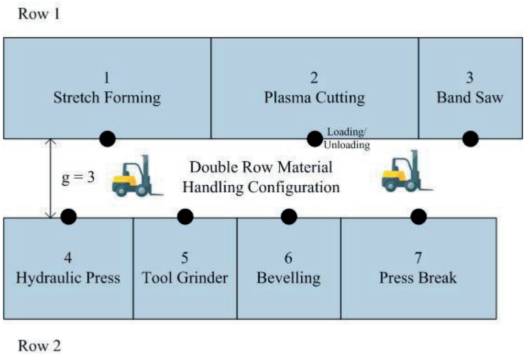


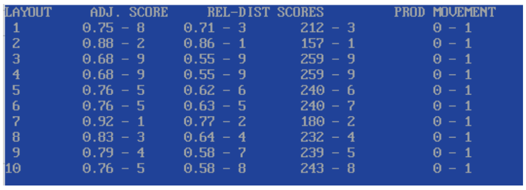

**Figure 2.** Existing or Current Layout.

The production sequence is Plasma Cutting, Band Saw, Bevelling, Press Break, Hydraulic Press, Stretch Forming, and Tool Grinder. From the process data flow obtained, an Activity Relationship Chart (ARC) is made based on qualitative criteria. ARC shows the relationship between each facility with the degree of closeness rating. The symbol are used are A fpr Abolutely Necessary, E for Especially Important, I for Important, O for Ordinary Closeness, U for Unimportant, X for Undesireble.

**Table 1.** Activity Relation Chart (ARC).

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|
| 1 | | I | I | A | U | U | A |
| **2** | | | O | O | U | X | A |
| **3** | | | | U | A | I | I |
| **4** | | | | | A | U | A |
| **5** | | | | | | U | I |
| **6** | | | | | | | U |
| **7** | | | | | | | |

General data of the machinery such as name, width, and ARC are inputted in BLOCPLAN. Then, iterated 10 times on the BLOCPLAN algorithm and obtained Adjective Score, R Score, and REL Dist Score data. The layout is randomly iterated 10 times by Random Layout. The random number of iteration is depend on the number of facility. From these values, the optimal layout is selected.



| LAYOUT | ADJ. SCORE | REL-DIST SCORES | | PROD MOVEMENT |
|---|---|---|---|---|
| 1 | 0.75 - 8 | 0.71 - 3 | 212 - 3 | 0 - 1 |
| 2 | 0.88 - 2 | 0.86 - 1 | 157 - 1 | 0 - 1 |
| 3 | 0.68 - 9 | 0.55 - 9 | 259 - 9 | 0 - 1 |
| 4 | 0.68 - 9 | 0.55 - 9 | 259 - 9 | 0 - 1 |
| 5 | 0.76 - 5 | 0.62 - 6 | 240 - 6 | 0 - 1 |
| 6 | 0.76 - 5 | 0.63 - 5 | 240 - 7 | 0 - 1 |
| 7 | 0.92 - 1 | 0.77 - 2 | 180 - 2 | 0 - 1 |
| 8 | 0.83 - 3 | 0.64 - 4 | 232 - 4 | 0 - 1 |
| 9 | 0.79 - 4 | 0.58 - 7 | 239 - 5 | 0 - 1 |
| 10 | 0.76 - 5 | 0.58 - 8 | 243 - 8 | 0 - 1 |

**Figure 3.** Adj Score, R Score, and REL Dist Score.

Based on the data value of the highest Adjective Score, the highest R Score, and the smallest REL Dist Score, the most optimal layout is layout 2.

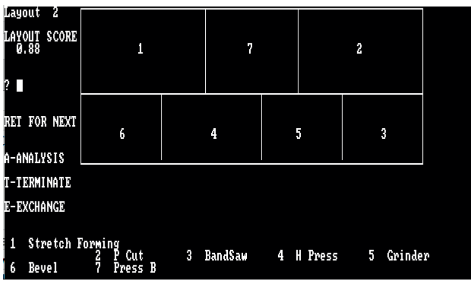



**Figure 4.** Optimal Layout.

Figure 4 shows the best layout position from BLOCPLAN. This position will be used as an input in GUROBI and Particle Swarm Optimization (PSO).

*Pseudocode for Gurobi Optimizer*

```
1:  Initialize index, parameter, and variable
2:  initialize the model
    model=gp.model()
3:  Set the objective function
    model.setObjective()
4:  Add the constraints
    model.addConstr()
5:  Optimize the Model
    model.optimize()
6:  Display the result
    print('machine position', i+1, in row, b+1)
```

*Pseudocode for PSO*

```
1:  Initialize parameter and variable
2:  initialize PSO Parameter
n_particle, n_dimesion, max_iteration
3:  initialize position
4:  set objective function
5:  add constraint
constraint.append()
6:  initialize particle
    position = np.random.uniform(lower_bound,
    upper_bound)
7:  initialize the gbest position and fitness
8:  iteration
    Update velocity
    Update gbest and fitness
    if fitness < particle.best_fitness:
        particle.best_position = particle.position
        particle.best_fitness = fitness
    if fitness < global_best_fitness:
        global_best_position = particle.position
        global_best_fitness = fitness
9:  Optimizer the PSO
    bounds = (lower_bound, upper_bound)
    initial_positions = initialize_particles(n_
    particles, n_dimensions, bounds)
    best_position = particle_swarm_optimization()
10: Display the optimal result
```

**Table 2.** TMHC comparison between BLOCPLAN, GUROBI, and PSO.

| | | | PSO | | | | |
|---|---|---|---|---|---|---|---|
| ROW | BLOCPLAN | GUROBI OPTIMIZER | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 |
| 1 | 1, 7, 2 | 1, 6 | 1, 2, 3, 4, 7 | 2, 4, 6 | 2, 3, 5, 6 | 4, 7 | 2, 3, 4 |
| 2 | 6, 4, 5, 3 | 2, 3, 4, 5, 7 | 5, 6 | 1, 4, 7 | 1, 4, 6 | 1, 2, 3, 5, 6 | 1, 5, 6, 7 |
| TMHC | 702.25 | 349 | 604 | 608 | 546 | 613 | 601 |

**Table 3.** TMHC comparison with and without BLOCPLAN

| BLOCPLAN | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Average |
|---|---|---|---|---|---|---|
| With BLOCPLAN | 484 | 546 | 531 | 469 | 527 | 511.4 |
| Without BLOCPLAN | 604 | 608 | 546 | 613 | 601 | 592.72 |

The result of TMHC from BLOCPLAN, Solver Gurobi, and PSO are compared. The TMHC calculation is obtained from the multiplication between the distance and the frequency of material movement from the machine *i* to machine *j*.

It shows that TMHC from Gurobi as a Solver still has the best value compared with others. PSO gives better enough results compared with BLOCPLAN. PSO gives a different result of TMHC in every run because it generates the random number as a particle at the beginning of the computing process.

For knowing the use of the sequencial used of three methods, it compared the TMHC value in PSO with and without BLOCPLAN.

The results of 5 times running with 100 iterations with PSO show that TMHC with optimal layout with BLOCPLAN is better than TMHC without optimal layout input from BLOCPLAN as an input.

The average TMHC with BLOCPLAN was 511.4 and without BLOCPLAN was 592.75. The average TMHC without BLOCPLAN is not better than the TMHC result from the BLOCPLAN algorithm and Gurobi optimizer. The best TMHC value in PSO with BLOCPLAN value in PSO with BLOCPLAN is 469.

Table 4 shows the computing time of Gurobi and PSO with the increase the number of data set. It tried to show how Gurobi and PSO perform with several number of data set (7, 10, and 15). As a solver that always gives the best solution instead of having limitations too. The limitation of the solver is the long computation time for larger data sets.

**Table 4.** Computing time Gurobi and PSO.

| Number of Data set | Gurobi (s) | PSO (s) |
|---|---|---|
| 7 | 2.19 | 0.5 |
| 10 | 5.05 | 0.75 |
| 15 | 32 | 0.86 |

So, for more number of the machine, PSO has better computing time.

## 5. Conclusion

From the research conducted, it can be concluded that sequential use of the BLOCPLAN algorithm as a constructed algorithm, Gurobi optimizer as an exact method, and PSO as a metaheuristic can be carried out and get better results. TMHC in PSO with BLOCPLAN as an input gives a better result than without BLOCPLAN. Thus, the proposed methods for optimizing the layout of facilities using constructed algorithms, exact algorithms, and metaheuristics sequentially can be used.

The layout result from the BLOCPLAN can be used as initial screening before moving to the computing process. Gurobi's performance in terms of computational time with a small data set is good, but for more data sets it is recommended to use the metaheuristic method.

For further research, these results can be compared with other metaheuristic methods such as Ant Colony Optimization or Simulated Annealing. Classification criteria for facility layout problems can be developed into dynamic conditions. The clearance value can be maximized to be a separate objective function. In addition, further testing is needed to ensure the effectiveness of using the three algorithms sequentially.

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