Implementation of Tabu Search Algorithm in Multi-Skilled Labor Scheduling for Assignment Problems

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Abstract. This study discusses the multi-skilled labor scheduling to accomplish all tasks where each labor has different skill to complete tasks than other labors. This case is known as the assignment problem. The objective value is to minimize the number of makespan or the total working time of all tasks until the daily orders (product) are fulfilled. Each labor can only do one task and not all of the labors are hired. We Solve the problem using tabu search algorithm. The characteristics of tabu search algorithm in finding solution are simple and flexible. Out of 100 iterations, the best solution ends at 613.879 seconds. Iteration lasts for 2 minutes and 31 seconds. The solution requires a total of 26 workers. Gluing needs 8 people, Wrapping needs 5 people, Tying needs 5 people, Strapping needs 4 people and Jointing needs 4 people.

Keywords: Assignment Problem, Multi-Skilled labor, Makespan, Tabu Search

1. Introduction
Scheduling, in the manufacturing industry area, involves scheduling across all lines and aspects of the industry. From conducting production machines schedule, the supply of raw materials schedules, transportation schedules and also the important thing is labor scheduling who work in the production area. Especially for the labors, the scheduling is not only when the labors starts to work, but also what kind of jobs will be worked by each labor. And one type of work that also crucial to be scheduled is manual work.

Manual work is a type of work that has a lot to do with human skills and does not use automated tools. In other words, the use of hands has very big role in work. This work is related with labor-intensive industries which has many workforce. Examples are gluing, strapping, and wrapping.

Every labor has different ability for different types of jobs. The ability can be seen in how fast the labor finish one task / product (second / unit). For example, there is labor who is faster in the gluing process compared to other labor, but he works slow to do wrapping. While other labors are the opposite of this labor, who are faster in wrapping. This causes differences in the placement of labors in each type of manual job. So the value of the total completion time (makespan) of labor positions will be different than other placements.

Besides of that, every day, output units that have to be finished from manual jobs are also different. It depends on the daily orders in a day. So, not all labors will be worked in a day because of limited tasks.
The study is to create an algorithm in labor scheduling (similarity with assignment problems) to produce the fastest completion time or minimum makespan (in second). Whereas the algorithmic approach will use the tabu search metaheuristic algorithm.

Tabu search algorithm has been widely used in solving scheduling problems in industrial areas. As in assembly line scheduling [9], preventive maintenance [8], scheduling of vehicle routing [6] and also on assignment problems [4]. This tabu search has the ability to short-term and adaptive memory to search the solutions to the optimal solution [4].

The algorithm will be processed using Macro Excel VBA 2007 coding with Intel Core I3 computer specifications and 4GB RAM.

2. Literature Review

2.1. Assignment problem
The labor scheduling has the same characteristic with assignment problem, where there are \( n \) labors assigned to \( m \) jobs / tasks, and each employee has different skills [10]. The Assignment Problem is a case that has the goal of finding optimization (maximizing and minimizing) of the objective function (income, cost, distance or time) by allocating resources (labors, employees, machines) to complete the tasks given [10].

This assignment problem determines production number and production capacity of the company. Therefore, without good management by solving assignment problems, it can reduce the productivity and profitability of the company [13]. The assignment problem is also decision making method [2].

In this study, we have total resources \((m)\) and total tasks / jobs \((n)\), where \( m \geq n \). Labor \( i \) \((i = 1, 2, ..., m)\) will be allocated to task \( j \) \((j = 1, 2, ..., n)\). In this case, the total number of labors \((m)\) is greater than number of jobs \((n)\). Every labor has different skills \((C_{ij})\). This can be illustrated as in the following matrix \((C_{ij})\) [2]:

\[
\begin{bmatrix}
C_{11} & \cdots & C_{1n} \\
\vdots & \ddots & \vdots \\
C_{m1} & \cdots & C_{mn}
\end{bmatrix}
\]

Figure 1. Skill Matrix upon Labor \( i \) on The Task \( j \) \((C_{ij})\).

This assignment problem has similarities with a balanced transportation problem, jobs to machines, people to projects, contracts to bidders, salespeople to territories, vehicles to routes, etc. But the main point of the assignment problem is “one worker is assigned to only one task” [7]. The illustration of the assignment problem can be seen as the Bipartite Graph below.

Figure 2. Bipartite Graph for Multi Skilled Assignment Problem.

Figure 2 above explains the use of 7 labors to be placed into 3 existing tasks. Two tasks (A and B) will be done by 2 employees, while task C is carried out by 3 employees. Each employee can only do one task. The expected objective function is to minimize total processing time / makespan [11].
2.2. Tabu search
The tabu search algorithm became one of the heuristic algorithms that was first developed by Glover in 1986. The basic concept of tabu search is to guide the search by avoiding being trapped in the previous conditions. The point is to prevent repetition of the same solution in iteration that has previously been passed [8].

3. Methods

3.1. The Math Model
We assume the labor set is \( I \), let \( I = \{1, 2, \ldots, m\} \). While the tasks assume into the set of \( J \), where \( J = \{1, 2, \ldots, n\} \). So the related variables are

- \( i \) = labor \( i \), where \( i \in I \)
- \( j \) = task \( j \), where \( j \in J \)
- \( C_{ij} \) = ability / skill of labor \( i \) to finish task \( j \) (second / unit)
- \( Q_{ij} \) = the number of products which employee \( i \) must complete for the task \( j \) in specific working hours \( T_{ij} \) (unit);
- \( T_{ij} \) = working hour used by labor \( i \) to do task \( j \) (second);
- \( O_j \) = Total unit products must be made in task \( j \) (unit); Shown in table 2.

The relationship between \( C_{ij}, Q_{ij} \) dan \( T_{ij} \):

\[
Q_{ij} = \frac{T_{ij}}{C_{ij}} \tag{1}
\]

\( X_{ij} \) = Condition whether labor \( i \) assigned in task \( j \) or not;

- \( X_{ij} = 0 \) means labor \( i \) not assigned in task \( j \).
- \( X_{ij} = 1 \) means labor \( i \) assigned in task \( j \).

Constraints:
1. Each labor can only do 1 task

\[
\sum_{j \in J} X_{ij} = 1 \quad \forall i \in I \tag{2}
\]

2. Every product made for each task must not be more or less than the desired order

\[
\sum_{i \in I} Q_{ij} = C_j \quad \forall j \in J \tag{3}
\]

3. The total working hour of each labor must not exceed available working hour \((T) = 7 \text{ hours} \times 60 \text{ minutes} \times 60 \text{ seconds}\)

\[
0 \leq Q_{ij} \leq \frac{T}{C_{ij}} \tag{4}
\]

Or

\[
0 \leq T_{ij} \leq T \tag{5}
\]

4. The value of \( X_{ij} \) is 0 or 1

\( X_{ij} = \{0, 1\} \)

5. Nonnegativity

\( i, j, m, n, C_{ij}, Q_{ij}, T_{ij}, O_j \geq 0 \)

Objective Function:

\[
\min \ z = \sum_{j \in J} \sum_{i \in I} C_{ij} Q_{ij} X_{ij} \tag{6}
\]

3.2. Case study
The study was done in the carton box manufacturing industry. There are 5 manual tasks to be carried out: gluing, jointing, strapping, wrapping and tying.
The number of labors is 60 people. The labor skills table for each task is shown below.

| No | Labor | Gluing | Jointing | Strapping | Tying | Wrapping |
|----|-------|--------|----------|-----------|-------|----------|
| 1  | A     | 46     | 15       | 18        | 111   | 177      |
| 2  | B     | 49     | 17       | 7         | 113   | 160      |
| 3  | C     | 49     | 17       | 6         | 130   | 176      |
| ... | ...   | ...    | ...      | ...       | ...   | ...      |
| 60 | BI    | 50     | 7        | 19        | 127   | 240      |

The order quantity for each task changes every day. For this study, the orders were taken on one day in February 2019. The numbers of order quantity are shown in table 2.

| No | Task   | Daily Order (unit) |
|----|--------|--------------------|
| 1  | Gluing | 8000               |
| 2  | Jointing | 12000             |
| 3  | Strapping | 15000           |
| 4  | Tying  | 1200               |
| 5  | Wrapping | 800               |

4. Result

After the tabu search algorithm is finished it is executed with the initial parameters:

a. Number of Elements = 60
   Indicates the number of labors is 60 people

b. Number of Iterations = 100

c. Number of Neighbor Solutions = 20

d. Tabu List = 10

The first iteration starts from the best solution = 744,792 seconds. This value gradually decreases until the 35th iteration which is below 700,000 seconds. Until finally the best solution ends at 613,879 seconds. This is also clearly illustrated in Figure 3.
For gluing, 8 employees are needed, namely employees number 38, number 45, number 57, number 41, number 16, number 4, number 35 and number 44. While jointing requires 4 employees. Strapping also requires 4 employees. Whereas tying and wrapping require 5 employees each.

| Task    | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|---------|----|----|----|----|----|----|----|----|----|----|
| Gluing  | 38 | 45 | 57 | 41 | 16 | 4  | 35 | 44 | -  | -  |
| Jointing| 60 | 37 | 20 | 36 | -  | -  | -  | -  | -  | -  |
| Strapping| 3  | 50 | 28 | 2  | -  | -  | -  | -  | -  | -  |
| Tying   | 34 | 12 | 11 | 13 | 47 | -  | -  | -  | -  | -  |
| Wrapping| 14 | 32 | 17 | 6  | 33 | -  | -  | -  | -  | -  |

Table 4 shows a total time (makespan) of completion for each job. The graph indicates that the makespan of jointing has the lowest value. The value of makespan strapping is slightly greater than jointing, even though both have the same number of labors (4 people). Wrapping and tying have almost the same value of makespan. They also have the same number of employees which is 5 people each. The highest makespan is gluing, this task also has the highest number of labors, 8 labors. The iteration process lasts for 2 minutes 31 seconds.

![Figure 4. Line Graphics of Impairment Solution](image)

5. Conclusion
From the execution tabu search algorithm with initial parameters: 100 iterations, 20 Neighbor Solutions and 10 Tabu lists, the optimum value reaches 613,879 seconds. This value is reduced from the initial iteration (0) of 744,792 seconds to 613,879 seconds. The 100 iteration process lasts for 2 minutes and 31 seconds. Gluing requires 8 workers, while wrapping requires 5 workers. Tying needs 5 workers, Strapping needs 4 workers and Jointing needs 4 workers.

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