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Application of the Nawaz-Enscore-Ham (NEH) algorithm for flow shop scheduling in a timber factory

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ABSTRACT

Scheduling is essential in production systems as it manages resource allocation and ensures precise and timely operations. A timber firm produces wooden hammocks and pallets to meet the demand for wooden pallets in the domestic market using a flow shop type production flow and the First Come First Served (FCFS) method. In December 2022, there was excess capacity due to a decrease in demand. Conversely, the company experienced a shortage of capacity in January due to a significant increase in demand for pallets from several companies. This situation resulted in idle time when switching to the next task, indicating that production capability was not being utilized to its full potential. The aim of this research is to provide production scheduling proposals to minimize makespan by applying the Nawaz-Enscore-Ham (NEH) method and the Integer Linear Programming (ILP) method. The proposed production scheduling with a lower makespan has been successfully obtained in this study.

1. Introduction

Industrial expansion in Indonesia is becoming more sophisticated, prompting businesses to constantly adjust to evolving advancements, particularly in the manufacturing sector. This adjustment involves innovation and enhancing productivity. Enhancing productivity entails optimizing the production process for efficiency. A company's effectiveness is demonstrated by the speed and punctuality of its production. Speed and timeliness can be achieved by scheduling production as effectively as possible. Scheduling production plays an important role in the effectiveness of the production process in a company [1]. Scheduling is the process of sequencing product manufacturing on several machines [2]. Production scheduling has a function or purpose to ensure that the production flow can run according to the planned time [3].

Minimizing makespan in flow shop scheduling poses significant challenges due to the NP-hard nature of the problem, requiring efficient optimization techniques [4]. Availability constraints caused by machine breakdowns further complicate scheduling, especially when considering stochastic breakdown starting times [5]. Additionally, the consideration of setup time, processing time, and transportation time as stochastic variables rather than deterministic values adds complexity to finding optimal schedules, necessitating the development of dominance relations to handle uncertainties and generate a set of dominating schedules [6].

Production scheduling in a timber factory can be optimized to minimize makespan using the Nawaz Enscore Ham (NEH) method and linear programming. The NEH method is a scheduling approach that has been utilized in various studies to minimize makespan, which represents the total time required to complete a set of jobs. It has been applied in different industries, including manufacturing and household sectors. NEH is often used in conjunction with other methods such as Longest Processing Time (LPT) and Shortest Processing Time (SPT) to enhance the scheduling process. Research has demonstrated that the NEH method is more

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effective in reducing makespan compared to existing methods like First Come First Serve (FCFS). Studies have indicated that implementing NEH can lead to a reduction in makespan by a certain percentage, ranging from 1.06% to 9.598% [7], [8], [9].

Integer linear programming, specifically mixed-integer linear programming (MILP), can also be used to optimize production schedules and minimize makespan [3], [10], [11]. A previous study revealed that a mixed-integer linear programming model for production planning in the sawmill industry successfully optimized the number of sawn timber product combinations and maximized profits. Linear programming has also been successfully applied to the scheduling of a multi-product flow shop in the pharmaceutical industry, considering energy consumption as a bi-objective function [12].

The necessity of using the NEH (Nawaz-Enscore-Ham) heuristic in flow shop scheduling problems arises from its proven efficiency and effectiveness in generating high-quality solutions within a reasonable computation time [13]. NEH algorithms play a crucial role in optimizing job sequences by prioritizing jobs based on various rules, such as the sum of processing times or moments like average, standard deviation, and skewness. Research has shown that enhancements to the NEH heuristic, like the Extended NEH (E-NEH) method, can further improve solution quality by selecting the most appropriate combination of moments during job ordering [14]. By predicting the demand for products and employing optimization methods like the NEH technique and linear programming, timber mills can establish streamlined production schedules, resulting in shorter completion times and enhanced resource efficiency [15].

Macuy Sejahtera Abad, later known as MSA, is a company that operates in the manufacturing sector, specializing in the production of wooden pallets and wooden hammocks. Established in 2015, MSA serves the domestic market's demand for wooden pallets and hammocks with a flow shop type of production system. A flow shop type of production refers to an environment where multiple machines are used to process a set of jobs. This production environment is common in industrial activity and can pose challenges in finding accurate scheduling solutions as the number of jobs and machines increases. Various solution methods, including heuristic and metaheuristic approaches, have been developed to address flow shop scheduling problems. A chaotic hybrid firefly and particle swarm optimization method, along with a developed version of local search, have been proposed as a solution method for scheduling flow shop production environments. The proposed method has been found to produce more reliable results compared to other algorithms in the literature [3], [16], [17], [18].

This company experienced excess capacity in December 2022. Meanwhile, in January 2023, a lack of capacity occurred due to the large demand for pallets from several companies. This condition resulted in idle time during the transition to the next job, indicating that the production capacity at MSA cannot be used optimally. The aim of this research is to provide production scheduling proposals to minimize makespan by comparing the best heuristic method, namely Nawaz Enscore Ham (NEH), to a linear programming approach.

2. Material and method

Scheduling is a vital decision-making process used in many real-time cases, where the goal is to optimize a desired objective [19]. Scheduling problems involve managing multiple tasks across various machines. In manufacturing, a task might signify a component of a product. Essential information for each task includes its processing duration on the machine, its readiness for processing, the deadline for completion, and its priority level. In this study, data were collected in the production division of MSA, which produces wooden pallets. Data collection was carried out through interview methods and direct field observations. The data obtained from interviews and observations consist of primary and secondary data. Primary data includes setup time and pallet production process data as well as pallet demand data, while secondary data includes general company data. This research compares the Nawaz Enscore Ham method and linear programming to find out which method is most suitable for use in the production conditions of MSA company.

2.1. Data processing

Fig. 1 shows the product produced by MSA. It has a production capacity of six days a week, with nine working hours per day. This means the company has a capacity of 234 hours per month. Table 1 shows the incoming received by MSA Company. The information on the cycle time for each job is shown in Table 2. According to the data presented in Table 3, there is surplus production capacity in December 2022, while in January 2023, the demand exceeds the available capacity.

Figure 1. Pallete wood

Table 1.
Incoming order

No.	Product type	Number
1	Double Deck Two way	220
2	Single Deck Four way	200
3	Single Deck Four way	330
4	Double deck Twoway Single	416
5	Single Deck Fourway	330
6	Single Deck Fourway	1000
7	Single Deck Fourway	330

Table 2.
Routing and processing time

Job	Bandsaw	Grinding	Planner	Nailgun
1	19,955	7,192	27,416	14,084
2	12,328	4,266	15,796	6, 556
3	23,441	7,139	26,461	10,857
4	37,771	13,596	51,840	26,630
5	20,234	7,035	26,061	10,816
6	70,981	21,624	77,150	32,895
7	23,901	7,492	25,759	11,112

Table 3.
Schedule generated by FCFS for December

No	Machine		Job 1	Job 2	Job 3
1	Bandsaw	start (hr)	0	19.995	24.221
		end (hr)	19.995	24.221	47.662
2	Gerinda	start (hr)	19,995	27.148	47.662
		end (hr)	27,148	31.413	54.801
3	Planer	start (hr)	27.148	54.564	70.360
		end (hr)	54.465	70.360	95.821
4	Nailgun	start (hr)	54.564	70.360	95.821
		end (hr)	68.648	76.916	106.678

Consequently, this study aims to suggest a solution by rescheduling Job 4 from January 2023 to December 2023, with the stipulation that the December 2023 task takes precedence over Job 4. This adjustment is intended to optimize the production capacity in December 2022 and reduce the excess capacity needed in January 2023.

2.2. *Nawaz Enscore Ham (NEH) algorithm*

The procedure for scheduling production using the Nawaz-Enscore-Ham (NEH) method involves several stages. The following are the scheduling stages using the NEH method [9]:

1. Calculate the total processing time for each job and sort the jobs based on the largest processing time.
2. Choose the first two jobs with the largest processing time, then calculate the makespan.
3. Choose the order of jobs with the smallest makespan.
4. Add the next job sequence to the previously selected job sequence.
5. If there is a new partial sequence that has the same partial makespan, choose the new partial sequence candidate with a smaller partial flow time. If they are the same, also select a partial sequence candidate randomly.
6. Continue the steps until all the jobs are scheduled and the sequence with the smallest makespan is achieved.

2.3. *Mathematical model for flow shop scheduling*

Flow shop production scheduling using linear programming can start with formulating the mathematical model.

<u>Indices</u>

i	Index of sequence
j	Index of job
k	Index of machine

<u>Parameters</u>

m	Number of machines
n	Number of jobs
t_{jk}	Processing time of job j on machine k

<u>Decision variables</u>

$Cmax$	Makespan of schedule
x_{ji}	1 if job j is on sequence i, 0 otherwise
s_{ik}	Start time of sequence i on machine k
c_{ik}	Completion time of sequence i on machine k

$$\text{Min } C_{max} \quad (1)$$

$$\sum_{i=1}^{n} x_{ji} = 1, \forall j \quad (2)$$

$$\sum_{j=1}^{n} x_{ji} = 1, \forall i \quad (3)$$

$$C_{ik} \geq S_{jk} + \sum t_{jk} X_{ji} \quad \forall j, k \quad (4)$$

$$S_i, k+1 \geq S_{ik} + \sum t_{jk} X_{ji} \quad \forall j, k = 1, \dots, k-1 \quad (5)$$

$$X_{ji} = 1 \ , \forall i = 4, j = 4. \quad (6)$$

$$C_{max} \geq C_{ik} \ \forall i, k \quad (7)$$

$$X_{ji} \in \{1,0\} \ \forall i, \forall i \quad (8)$$

Eq. (1) denotes the objective function to minimize makespan. Eq. (2) guarantees that each job occupies only one sequence. Eq. (3) ensures that each sequence is occupied by only one job. Eq. (4) calculates the completion time of each job on each machine, whereas Eq. (5) calculates the start time.

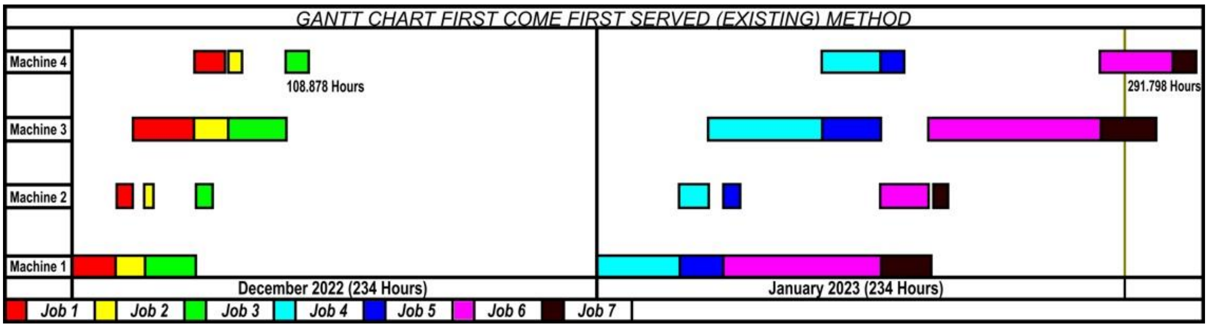

Figure 2. Gantt Chart of existing scheduling rule

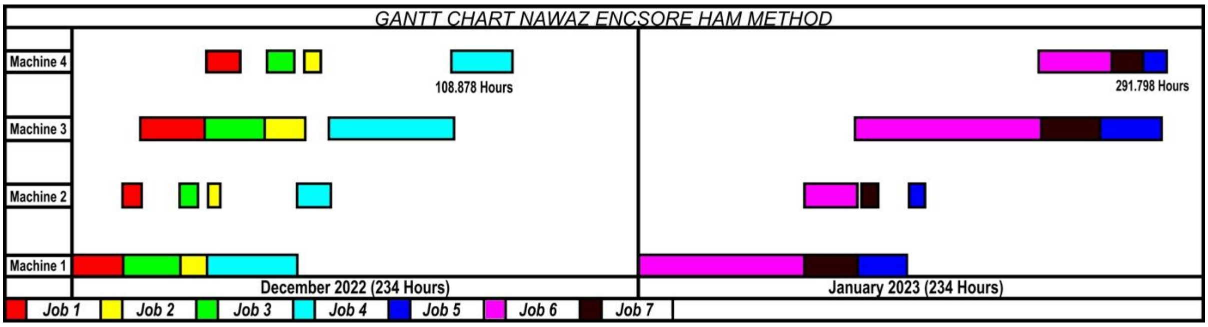

Figure 3. Schedule obtained by NEH

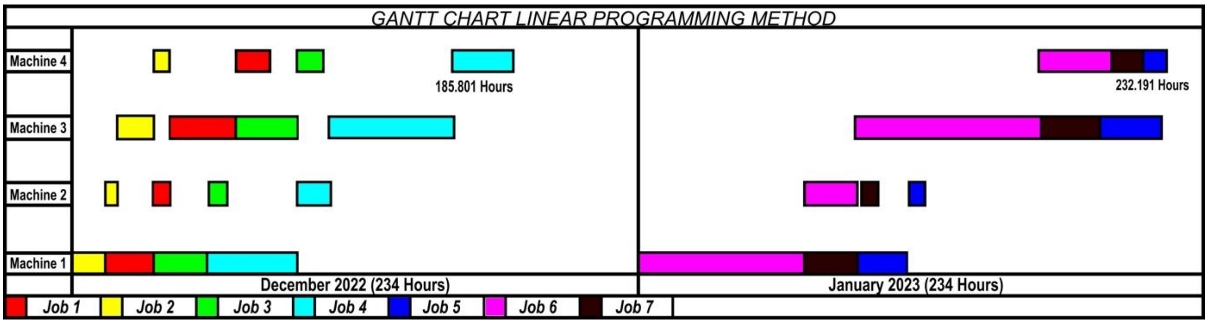

Figure 4. Schedule obtained by ILP

Eq. (6) ensures that job 4 is completed after jobs 1, 2, and 3, or in sequence 4. Eq. (7) enforces that the maximum completion value is greater than or equal to the value of the entire completion time. Eq. (8) expresses the binary variables.

3. Results and discussions

To complete the incoming order with the minimum makespan, the NEH scheduling method was applied to determine the job sequence. Fig. 2 shows the schedule obtained by existing scheduling rule (FCFS). The results for scheduling using the Nawaz Enscore Ham method are shown in Fig. 3. The mathematical model was executed using Lingo software and the results is shown in Fig. 4.

Production scheduling in the timber industry can be optimized using linear programming techniques. By formulating mathematical models, researchers have been able to determine the optimal number of product combinations, minimize costs, and maximize profits [1]. These models consider factors such as production costs, raw material costs, and purchasing costs to create efficient production plans. Additionally, the scheduling of harvesting activities within and between cut blocks has been optimized using mixed-integer linear programming models, considering the precedence relationship among activities. These models aim to minimize overall costs by determining the start and end times of each activity, considering machine movement times [20]. Overall, linear programming has proven to be a valuable tool for optimizing production scheduling in the timber industry. Fig. 4 shows the Gantt chart for the completion of all jobs. The job sequence is 2-1-3-4 with a total makespan of 185.5 hours. Only on machine 1, the job sequence can be executed without waiting time.

4. Conclusions

The makespan value for the existing scheduling in December 2022 is 106,678 hours with the job order 1-2-3. Meanwhile, for January 2023, it is 271,798 hours with the job order 4-5-6-7, and delays occur. The makespan value for the Nawaz Enscore Ham scheduling in December 2022 is 185,500 hours with the job order 1-3-2-4, and for January 2023, it is 232,392 hours with the job order 6-7-5, with no delays. The makespan value for linear programming scheduling in December 2022 is 185,501 hours with the job order 2-1-3-4, and for January 2023, it is 232,391 hours with the job order 6-7-5, with no delays. The Nawaz Enscore Ham method and linear programming have equally good performance compared to the first-come-first-serve method.

Declaration statement

Yusraini Muharni: **Conceptualization, Methodology, Supervision.** Ade Irman: **Resources, Validation.** Hilal Lazuardi: **Data Collection, Writing - Original Draft.** Evi Febianti: **Resources, Validation, Kulsum: Resources, Visualization, Investigation.** Lely Herlina: **Formal analysis. Validation.** Muhammad Adha Ilhami: **Mathematical modelling and Software**. Hartono: **Review & Editing**.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article or its supplementary materials.

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