Mixed-Integer Linear Programming Model for Production Planning: A Case Study at Sawn Timber Production

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ABSTRACT

The sawmill industry is an industry that processes logs into sawn timber products through several processes to maximize profits and meet customer demand. The process involves essential operations that have to be coordinated to get the desired product with the available resources optimally. Efficient operations can be achieved through optimal production planning by considering some factors to optimize the number of sawn timber product combinations. Optimal production planning is expected to have an impact, such as reducing the use of raw materials that can affect inventory and procurement. In this research, the author has developed a mathematical model for production planning to determine the optimal number of sawn timber product combinations. Problems were solved using mixed-integer linear programming methods with mathematical modeling that aimed for maximizing profit. Production costs, raw material costs, and purchasing costs were critically considered in this mathematical modeling. The result showed that using the developed model could integrate the factors above, fulfill the demand, and increase company income.

1. Introduction

The sawmill industry is an industry that processes logs into various sizes of sawn timber that is ready for use. The processing of logs is through various stages such as the cleavage, ripping process, and cutting process [1], [2], [3]. The processing of log into sawn timber starts from the classification of the log conforming to length and diameter [4], [5]. Then, the first cutting process of the log to sawn timber wood called primary saw produces cant and flitch. In this process, the cant and flitch are cut into sawn timber in various dimensions at the end [6], [7]. The conversion process into various sizes of sawn timber is intended to maximize profits and fulfill customer demand [8].

The conversion process involves a critical operation that has to be coordinated to obtain the desired product with the available resources optimally. Efficient operation can be achieved through optimal production planning by considering the lumber recovery factor or lumber yields [8], [9], [10]. The lumber recovery factor is the percentage or ratio of the volume of sawn timber product output to the volume of log input that is processed

in the sawmill [8], [11], [12]. Several factors that affect the system of production processes and lumber recovery factor are The number of sawn timber products combination based on customer demand and the raw materials, the availability of raw materials based on the diameter and length of the log, the logs processing into sawn timber products, and the machine tools [5], [13], [14], [15]. Therefore, production planning by considering the factors above needs to be integrated appropriately to achieve the goal of proper system and efficient production [6], [16]. Furthermore, by optimizing the production planning, the sawmill industry can reduce the amount of log used, log cost, and log waste [17], [18], [19], [20], [21].

In production planning, the solutions model can be obtained from linear programming models [22]. Linear programming is a model of analysis that can be applied in using limited resources to obtain the optimal solution, such as maximum profit or minimum cost in a mathematical model [23], [24]. Several previous studies apply linear programming models for production planning sawmill problems. Alvarez and Vera [25] present mathematical modeling that considers an annual planning period and solving some uncertainties. Farrell and Maness [26] examine a mixed-integer linear programming model to maximize the wood manufacturing process. Koch, et al. [27] study integer linear programming models to reduce the cutting process costs in the sawmill industry. Lindner, et al. [28] propose a study to minimize the production costs by optimizing engine settings in sawmill operation. Vanzetti, et al. [6] suggest an optimization approach for multi-period production planning in the sawmill. In addition, Broz, et al. [29] highlight a goal programming application of several objectives: maximizing profit, minimizing loss of material, minimizing inventory, and minimizing the unmet demand in making decisions in a sawmill. The previous studies show that the linear programming model can help the sawmill industry solve problems in sawmill production planning and improve production planning.

In this research, the method used was mixed-integer linear programming with the goal of profit maximization. The model used was a model by Vanzetti, et al. [6] with some modifications to adjust it with the company's actual conditions. The purpose of the model was to determine the optimal number of sawn timber products by considering the efficiency of processing logs into sawn timber products. Modifications made were in the objective function and the addition constraint function regarding the sawing machine's production capacity. The addition of this constraint function was intended so that all elements in production planning could be simultaneously assessed according to the industry's limits. This research implemented ILOG CPLEX to process the data. One of the advantages of using ILOG CPLEX is the Optimization Programming Language (OPL) as Algebraic Modeling Languages (AML) that is believed to make the coding process easier and simpler [30]. This study contributes to production planning by developing a sawn timber production planning model by considering machine capacity.

The paper was structured as follows; Problem statement, assumptions, notation, mathematical modeling, case study, and sensitivity analysis procedure were described in Section 2; whereas Section 3 presented the results and discussion. Section 4 contained conclusions and suggestions.

2. Methods

In this section, the article describes problems, assumptions, and mathematical models. This paper modified the proposed model proposed by Vanzetti, et al. [6]. a detailed description is presented in the next subsection.

2.1 Problem Statement and Assumptions

During the production process, the primary key that has to be maximized is the production planning to determine the type of sawn timber products and the volume. Sawn timber products consist of various types and sizes. Various assumptions were discussed in this research. 1) There is a concept regarding the primary order and side order as sawn timber products. Main order and side orders are the sawn timber products obtained after operating through three production processes. Main orders are stacks of sawn timber products that are ordered from customers. Side orders are stacks of sawn timber products that are non-ordered from customers. Non-order products are products that could be stored and sold when an order is placed. The purpose of non-order products is to maximize the processing logs into sawn timber products, so the wood waste from the production process can be reduced. 2) The type and size of the primary order and the side order adjusted to the products. 3) The stages of the production process from log to sawn timber products are carried out directly. This assumption is used to systematize, integrate and aggregate the sawing process. In this study, the model developed was a model for finding the optimal number of combinations of sawn timber products that correspond to the primary order and the side order.
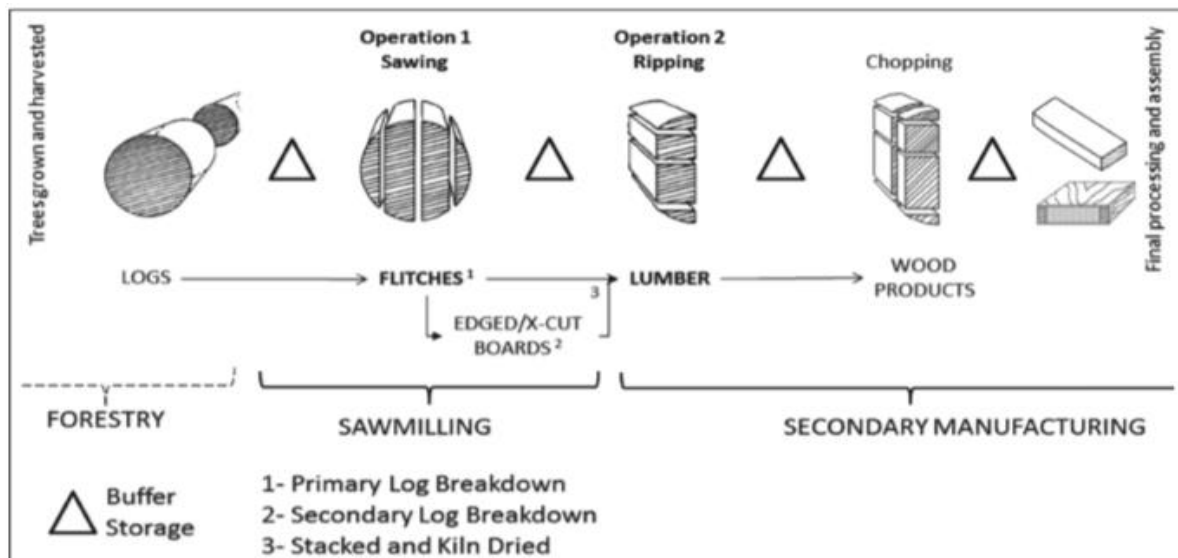

Fig. 1. Sawmilling production process (adapted from [28])

2.2 Notation and Mathematical Modeling

In this section, a notation and mathematical model formulation are presented. Component models that are formulated consist of objective function and constraints.
Notations:

d	: Diameters of logs
l	: Length of logs
i	: Sawn timber products (for main product)
j	: Sawn timber products (for side product)
p	: *Cutting pattern*

Parameter:

VFi_i ; VFi_j	: Sawn timber products of main product i or side product j that sold (m³)
PVi_i ; PVi_j	: The selling price of sawn timber products of main product i or side product j (IDR/m³)

Qb_{dl}	: Purchased logs diameter d and length l from the supplier (m³)
Crm_{dl}	: Purchased logs cost diameter d and length l (IDR/m³)
Qt_{dl}	: Old logs or stored logs diameter d and length l that processed (m³)
$Crmp_{dl}$	: Old logs cost or stored logs cost diameter d and length l (Idr/m³)
Qp_{dlp}	: Total of all logs diameter d and length l that processed (m³)
$Cprd_{dlp}$	: Production cost for CP p applied to logs of diameter d and length l (IDR/m³)
x_p	: Indicates whether sawmill process is done or not, if x_p : 1 sawmill process is done
Qa_{dl}	: Purchased logs diameter d and length l that processed (m³) (m³)
Ib_{dl}	: Total of purchased logs that stored (m³)
It_{dl}	: Total of old logs or stored logs diameter d and length l that available (m³)
Fi ; Fj	: Proportion of logs processing into sawn timber products of main product i or side product j (%)
Qpi_{dlp} ; Qpj_{dlp}	: Total of logs diameter d and length l that processed into sawn timber products of main product i or side product j (m³)
ρ_{dpi} ; ρ_{dpj}	: Conversion factor or the value of lumber recovery ratio of main products i or side product j
Pi_i ; Pj_j	: Total production of sawn timber product of main product i or side products j (m³)
DMi_i ; DMj_j	: *Demand* of sawn timber products of main product i or side product j (m³)
BM	: *Big* constant
t_{dlp}	: Operating time for processing a log diameter d and length l using CP p (h).
ts_p	: Setup time for using CP p (h).
$Tmax$	: Maximum operation time for a sawmill (h)
$Capmax$	: Maximum production capacity on the sawing machine (m³)

This mathematical model is used to optimize profit in production planning. Mathematical to describe this problem is as follows :

Equation (1) is the objective function of the problem to maximize profit. The components of the objective function are presented in equations (2)-(4). The equation describes the mathematical model of sales revenue or income. The mathematical model of raw material cost is explained in equation (3). The mathematical model of production cost is formulated in equation (4).

$$\text{Max Z} = \text{In} - (\text{CR} + \text{CPr}) \tag{1}$$

$$In = \sum_{i,j}(VFi_iPVi_i) + (VFj_jPVj_j) \tag{2}$$

$$CR = \sum_{d,l} Qb_{dl}Crm_{dl} + Qt_{dl}Crmp_{dl} \tag{3}$$

$$CPr = \sum_{d,l,p} Qp_{dlp}Cprd_{dlp} \tag{4}$$

The constraint considers the availability of raw materials and inventory, log processing, and production process of main product and side product to meet the demand

satisfaction. Constraint in the availability of raw materials and inventory is formulated in equations (5) and (6). Equation (7)-(13) describes the constraint of the availability of log processing. The capacity limit is shown in equation (14). The constraint of a mathematical model of production and demand satisfaction is formulated in equation (15)-(18).

$$\sum Qb_{dl} = Qa_{dl} + Ib_{dl} \quad \forall d, l \tag{5}$$

$$It_{dl} \geq Qt_{dl} \quad \forall d, l \tag{6}$$

$$\sum_{d,l,p} Fi \, Qp_{dlp} = Qpi_{dlp} \tag{7}$$

$$\sum_{d,l,p} Fj \, Qp_{dlp} = Qpj_{dlp} \tag{8}$$

$$\sum_{p,d} Qpi_{dlp} \, \rho_{dpi} = Pi_i \quad \forall l, i \tag{9}$$

$$\sum_{p,d} Qpj_{dlp} \, \rho_{dpj} = Pj_j \quad \forall \, l, j \tag{10}$$

$$\sum_{p} Qp_{dlp} = Qt_{dl} + Qa_{dl} \quad \forall d, l \tag{11}$$

$$\sum_{d,l} Qp_{dlp} \leq BM \, x_p \quad \forall p \tag{12}$$

$$\sum_{d,l,p} Qp_{dlp} \, t_{dlp} + \sum_{p \epsilon P} ts_p \, x_p \leq Tmax \tag{13}$$

$$\sum_{d,l,p} Qp_{dlp} \leq Capmax \tag{14}$$

$$Pi_i \geq VFi_i \, \forall \, i \tag{15}$$

$$Pj_j \geq VFj_j \, \forall \, j \tag{16}$$

$$VFi_i = DMi_i \, \forall \, i \tag{17}$$

$$VFj_j = DMj_j \, \forall \, j \tag{18}$$

2.3 Case Study

This research was conducted in Indonesia's Wood Industry. In formulating a mathematical model, the first step needed was to describe the industry's existing sawmill system. The log used is a teak log sent by KPH Perum Perhutani (State Forestry Company in Indonesia) as the supplier. The log used consisted of two sizes, namely AII with a 20-29 cm diameter and AIII with a diameter of ≥ 30 cm. Several stages of the production process from log to sawn timber products, specifically: sawing using a Band Log Saw machine, ripping using a Band resaw machine, and chopping using a Cross-Cut machine. The stages of the production process can be seen in Fig. 1.

The logs used are AII and AIII logs. Each log was divided according to length, starting from l1 to l5. l1 showed the sum of all logs that had a length of 50-90 cm, l2 for logs with a length of 100-140 cm, l3 for logs with a length of 150-190 cm, l4 for logs with a length of 200-240 cm, and l5 for logs with a length of 250 -290 cm. Then, there were ten sawn timber products, namely Jeblosan Board, Garden Furniture, Flooring, Decking, Skirting, Longstrip, and Parket Block, included in the main product. Then, Parket Stok, Reng, and List were included in the side product.

Logs were processed using three machine units, namely PGM 1, PGM 2, and PGM 3, with a total production capacity of 10,404 m3. Sawmill operation time was 8 hours per day for six working days a week. In a year, IK Brumbung's workday was 289 days. When processing logs into sawn timber products, there was a proportion value used in producing main products and side products. The proportion value of the use of logs into the main product was 80% of the total logs processed, and the side product was 20% of the total logs processed. Table 1 until Table 3 shows the data used in this study.

Table 1. The availability of logs (AII)

Length	Stored Logs		Purchased Logs	
	Volume (m³)	Cost (IDR)	Volume (m³)	Cost (IDR)
11	6.030	2,328,042	6.030	2,360,388
l2	343.776	2,834,346	343.776	3,291,644
l3	270.993	3,035,619	270.993	3,212,664
l4	143.678	3,044,953	143.678	3,231,399
l5	21.588	3,199,186	21.588	3,453,636

Table 2. The availability of logs (AIII)

Length	Stored Logs		Purchased Logs	
	Volume (m³)	Cost (IDR)	Volume (m³)	Cost (IDR)
11	221.770	4,446,927	421.25	4,456,572
l2	597.530	4,872,151	1253.6	4,884,165
l3	302.880	4,924,974	1279.42	5,057,298
l4	256.970	6,006,590	1580.39	6,261,820
l5	1.740	6,637,329	188.19	6,733,965

Table 3. The demand for sawn timber products

Sawn Timber Products	Volume (m³)	Sawn Timber Products	Volume (m³)
Jeblosan Board	94.653	RST Other	5.248
Garden Furniture	82.729	Parket Block	192.120
Decking	121.711	Parket Stok	0
Longstrip	253.759	Reng	176.452
Flooring	1206.444	List	0

2.4 Sensitivity Analysis

Sensitivity analysis is an analysis used to determine the impact of changes in some parameters in the production system's performance in generating the decision variable, so it can be known what parameters are sensitive to the model being built. In this research, local sensitivity analysis was done by only looking at changes in the model output to changes in input parameters around the specific value of x. The method used was One-At-a-Time (OAT), or a method that analyzed changes in one parameter value. At the same time, the other parameter values were fixed [31]. In this research, sensitivity analysis was done by changing the volume of sawn timber products demand.

The 12 parameters were used to see the effect of changes in the volume of demand on the decision variable or output. Demand on parameter 1 decreased by 0.5% from the actual demand, parameter 2 decreased by 0.4%, parameter 3 decrease by 0.3%, parameter 4 decrease by 0.2%, parameter 5 decrease by 0.1%, parameter 6 decrease by 0.004%, parameter 7 increase by 0.004%, parameter 8 increase by 0,1%, parameter 9 increase by 0.2%, parameter 10 increase by 0.3%, parameter 11 increase by 0.4%, and parameter 12 increase by 0.5%.

3. Results and Discussion

3.1 Productions Planning with ILOG CPLEX

This section describes the results of production planning to maximize profits. Table 4 shows the volume of sawn timber products produced from data processing using ILOG CPLEX. The volume indicated that all demands were met and additional production outside of demand for both the main products and the side products. This additional production later became a ready-stock product. From Table 4, it is known that the proportion of production of sawn timber products for main products and side products was appropriate where the company should produce more of the main products than the side products.

Table 4. The volume of sawn timber products produced

Sawn Timber Products	Volume (m³)	Sawn Timber Products	Volume (m³)
Jeblosan Board	457.3707	RST Other	91.1818
Garden Furniture	181.4165	Parket Block	657.457
Decking	191.7778	Parket Stok	21.3076
Longstrip	372.4754	Reng	176.452
Flooring	1206.444	List	31.2195

After solving the model using ILOG CPLEX, the objective function's value was equal to Rp 74,406,574,908 in a yearly planning horizon, as seen in Fig. 2. These results indicated that the model used gave a positive profit value. There was an increase in revenue from these results as much as 29%, or equal to Rp 16,510,574,908 from the actual conditions.

The proposed model's increase in income occurs due to the proposed model used in the optimal condition. It corresponds to where the proposed model, an additional constraint function regarding production capacity on the sawing machine, appeared. Besides, in actual condition, some demand for sawn timber products was not fulfilled. Therefore, using the proposed model, production planning is projected to increase processing logs' efficiency into sawn timber products in meeting demand.
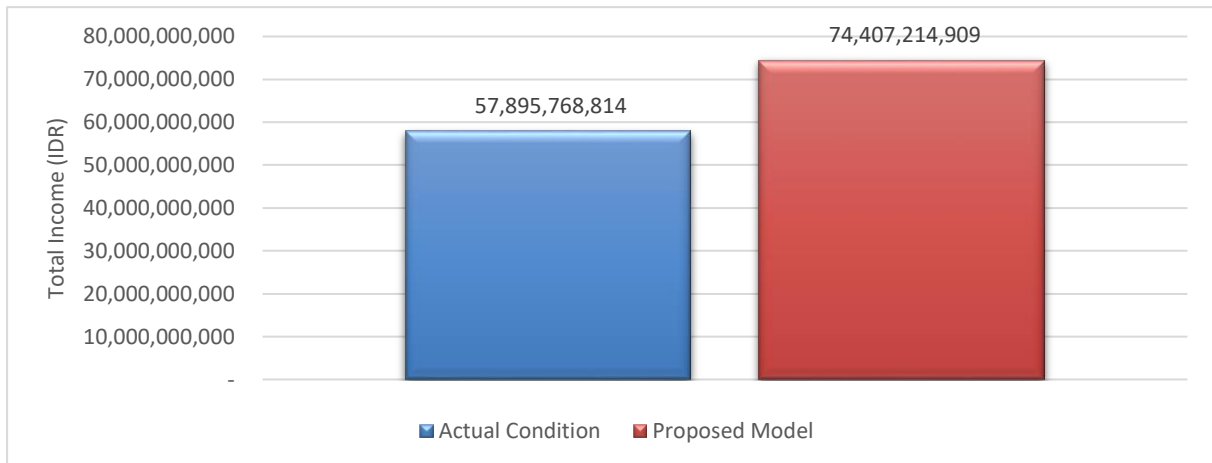
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Fig. 2. Income (IDR) Comparison between the Actual Condition and Proposed Model

3.2 Sensitivity analysis

Fig. 3 shows a graph of changes in all sawn timber products' total volume for each parameter. The volume of sawn timber production used as a comparison is indicated in the initial parameters. There was a change in production volume for all sawn timber products in parameters 1, 2, 3, 4, 5, 8, 9, 10, 11, and 12. However, in parameters six and parameter 7, the production volume did not change for all sawn timber products. These results indicate that the proposed model gives different results when the demand volume decreases by 0.005% and increases by 0.005%. The model postulates different results when the demand volume is below the decrease of 0.005% and below the increase of 0.005%. The graph above also shows that the change of production volume will move linearly as the parameter value change. Thus, it can be seen that the proposed model is sensitive to changes in demand above 0.004% and below 0.004%.
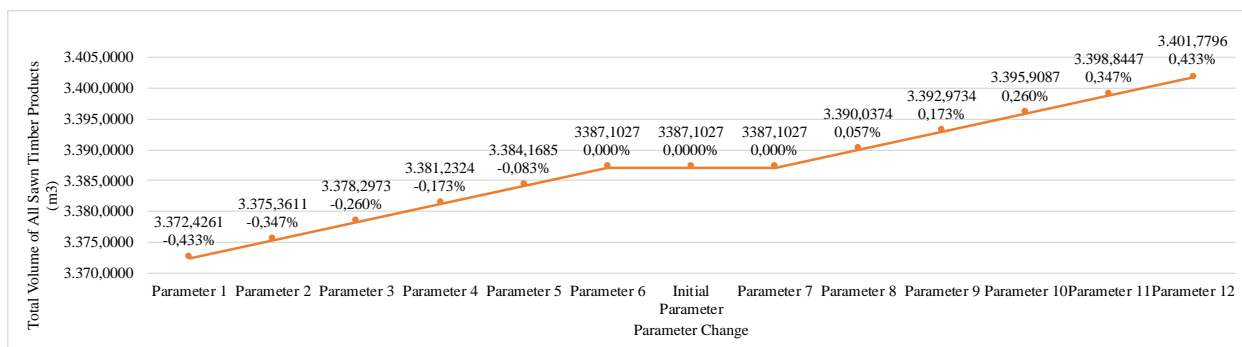

Fig. 3. Percentage Change in Production Volume of Sawn Timber Products

4. Conclusion

One of the sawmill industry's problems is to fulfill the demand by increasing the efficiency of using logs to maximize profit. In increasing the level of efficiency, optimizing production planning can be used. In this study, a model of Mixed-Integer Linear Programming for optimal production planning was proposed. This model has an objective function to maximize the profits obtained from calculations by considering the sale of sawn

timber products, production costs, and the cost of purchasing logs. Then, production planning also considered the availability of raw materials, log processing, and production products to meet demand satisfaction. From the calculation results, the proposed model successfully integrated the factors above and also could solve problems in sawmill production planning, especially maximize the profit and meet the demand satisfaction for sawn timber products. Further research can be developed by considering each month's time period in a yearly planning horizon and exercising different cutting patterns in log processing into sawn timber products.

Acknowledgments

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