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Optimal Kiln Dry Allocation for Dry Timber Preparation to Minimize Cost

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Abstract: Optimization models are increasingly developed for planning and scheduling in manufacturing of natural resources. However, the uncertainty of material from natural resources makes it more difficult to develop a model. In this paper, we concern about the cost of dry timber preparation for finishing process in a wood-board manufacturer. Based on characteristics of the material and wood-board production process, we develop two models to minimize transportation and drying cost of wood supply. The models consider the capacity of facilities, distances among facilities, and timber specification-based drying periods. The model is solved using linear programming, result in drying allocation of kiln dry's chambers that gives the minimum cost of the process. A sensitivity analysis is conducted to demonstrate the effect of variation of internal capacity and external capacity to the objective function value. The results show that the total cost is more sensitive to the variation of the external capacity of kiln dry than the variation of the internal capacity.

Keywords: Material planning, linear programming, wood-board manufacturing.

Introduction

Many studies are conducted to optimize furniture and lumber production and supply chain because furniture is a unique and important industry. Komsiyah *et. al.* [1] develop a fuzzy goal programming to solve a production planning problem in one furniture manufacturer. Robb *et al.* [2] develop a model to explore the link of operations practice and financial performance of 72 furniture manufacturers located in China. Michlesen *et al.* [3] introduce a method to calculate eco-efficiency in an extended supply chain using a case study from a furniture company in Norway. Forget *et al.* [4] develop a multi-behavior agent model to increase the agility of the supply chain and promote collaborative management for a timber industry. This paper proposes a model to optimize planning and scheduling of sawing and drying processes in a furniture manufacturer in Indonesia.

Gaudreault *et al.* [5] propose two models formulations for drying and finishing processes using Mixed Integer Programming (MIP) and Constraint Programming (CP) with an objective to minimize tardiness of the quantities ordered by customers. Other research by Gaudreault *et al.* [6] proposes a mathematical model to plan and schedule the softwood timber supply chain with two-phase planning and bottleneck-first planning. The research results in planning and scheduling to minimize tardiness of customer order. Marier *et al.* [7] propose a MIP model to define an optimal loading pattern in the kiln drying process to minimize order lateness. The second model defines timber allocation for each chamber in the kiln dry to minimize the usage of chambers and also to minimize the cost of the drying process. By minimizing cost, planning of the finishing process can be predetermined and the delivery time of finished goods can be predicted. On time scheduling of the dry timber preparation and finishing process will minimize order lateness and total cost, simultaneously. Maturana *et al.* [8] propose a mathematical model for scheduling problem at a sawmill to estimate the required log supply and fulfilling orders with minimum cost. Wery *et al.* [9] conduct a study to define an optimal sawing pattern using Optitek. Ouhimmou *et al.* [10] develope a mathematical model to minimize cost at a competitive level of service for one furniture company. The decisions include procurement, inventory, outsourcing, and demand allocation policies.

From the literature review, there is no mathematical model for two processes in sawmill and kiln dry including outsourced kiln dry in a furniture manufacturer. In this paper, firstly we propose a model to allocate timber to drying facilities with the minimum cost of transportation, production, and holding cost. Allocation result will be used to minimize chamber capacity usage of kiln dry in the second model.

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Methods

Model Development

This paper addresses a real process planning and operations scheduling problem of dry timber preparation, specifically dealing with the cost of timber allocation in the kiln dry. Dry timber availability is the main constraint in for the allocation problem. Based on the characteristics of wood, the timber supply chain is similar to other wood industry: timber material comes from forest contractors to sawing facilities and continues to value-added mills [6].

We are dealing with two sawing facilities that process log into the various size of timber and four drying facilities to produce dry timber for the finishing process, as shown in Figure 1. Each sawmill can produce timber according to the size needed by the finishing process. Timber from sawmill A is only sent to kiln dry (KD) 1, 2 and 3, while the output of sawmill B is sent to kiln dry 3 and 4. Kiln dry capacity is based on one cycle drying. For a certain thickness of timber, the drying period is only 10 days. Therefore, for this thickness, the kiln dry can be run three cycles in a month.

This paper proposes two models for dry timber preparation with minimal total cost. The first model deals with timber allocation at kiln dry facilities, that minimizes the costs of transportation, processing, and holding. The second model proposes the allocation of timber in the chamber at each kiln dry facilities with the objective function of minimal chamber usage. The models are executed by considering sawmill capacity, the thickness of timber, kiln dry capacity, transportation, processing, and holding costs of each facility and drying period. The problem becomes complex because different timber thickness needs different drying duration.

A conceptual model is created based on the real process using the manufacturer's historical data set and assumptions.

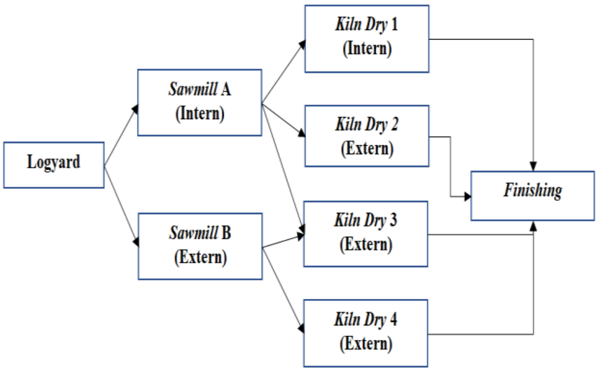

Figure 1. Dry timber preparation process

Assumptions: (1) There are two sawing facilities and four drying facilities with similar capabilities. (2) The log is always available to fulfill sawing capacity. (3) There is route capacity for each facility. (4) Drying duration defines drying cost and each drying facility have own cost standard. (5) Specification of timber determines drying duration. If there are two or more timber thickness in one chamber, then drying duration follows the duration the thickest one.

Notations:

t : the thickness of sawn timber
s : sawmill
k : kiln dry
i : chamber
W_t : the cycle of drying process for sawn timber with thickness t

Parameters:

C_{sk}^{m} : transportation cost from sawmill s to kiln dry k
C_{s}^{h} : holding cost of entrusted timber at the sawmill s
C_{tk}^{d} : transformation cost of sawn timber t at kiln dry k
P_k : the capacity of kiln dry k
P_i : the capacity of chamber i
D_t : coefficient of drying capacity usage for sawn timber t
B_{st} : maximal supply of sawn timber t from sawmill s

Variable:

X_{tsk} : Volume of thickness t of sawn timber supplied from sawmill s and deliver to kiln dry k
Y_{ikt} : Volume for t thickness of sawn timber processed in a chamber i at kiln dry k
X_{it} : Volume of thickness t of sawn timber processed at chamber i
R_{ik} : $\begin{cases} 1, if\ chamber\ i\ at\ kiln\ dry\ k\ is\ used \\ 0, other\ wise \end{cases}$

Sawn Timber Allocation with Minimal Cost

$$\min Z = \sum_t \sum_s \sum_k C_{sk}^{m} \, . \; X_{tsk} + \sum_t \sum_s \sum_k C_{tk}^{d} \, . \; X_{tsk} + \sum_t \sum_s C_{s}^{h} \, . \; X_{ts} \quad (1)$$

s.t.

$$\sum_k X_{tsk} \leq B_{st} \;, \forall s, t \quad (2)$$
$$\sum_t \sum_s D_t \, . \; X_{tsk} = P_k, \forall k \quad (3)$$
$$\sum_s \sum_k X_{2sk} = 0.8 \sum_s B_{2s} \quad (4)$$
$$\sum_s \sum_k X_{3sk} = 0.8 \sum_s B_{3s} \quad (5)$$

In this model, sawn timber with various thickness from the two sawmills is allocated to four kilns dry. The objective function of the model is to minimize transportation, processing, and holding costs as described in eq. 1. The total sawn timber allocated in all kiln dry should be less than the maximum supply of each sawn timber thickness and sawmill (eq. 2). The total sawn timber processed at a kiln dry should be equal to the capacity of the kiln dry, where the capacity usage (D_t) is based on the drying period for each thickness t of sawn timber (eq.3). For example, the coefficient of D_2 of 0.33 means 10 days usage of available monthly capacity. Based on finishing priority usage, 80% of sawn timber with a thickness t_2 and t_3 must be processed at kiln dry (eq. 4 and 5).

Minimum Chamber Allocation

$$min\ Z \ = \sum_{i,k} R_{ik} \tag{6}$$

s.t.

$$\sum_i \sum_s Y_{ikt} \ \le \sum_s X_{tsk} \ , \forall\, t, k \tag{7}$$

$$\sum_t \frac{Y_{ikt}}{W_t} \ \le P_i \ , \forall i, k \tag{8}$$

$$\sum_t Y_{ikt} \ \le M\, R_{ik} \ \ , \forall i, k \tag{9}$$

$$R_{ik} \begin{cases} 1, & \text{chamber used} \\ 0, & otherwise \end{cases} \tag{10}$$

In the second model, we try to minimize the number of chamber usage in each kiln dry (*k*) as shown in eq. 6. The total sawn timber processed in all chambers should be less than the maximum supply allocation of each sawmill to each kiln dry (eq. 7). The total sawn timber processed at the chamber should be equal to the capacity of the chamber, where the drying cycle for each thickness (W_t) is based on the drying period for each thickness t of sawn timber (eq. 8). For example, the drying cycle of t_2 is 3, means 3 cycles in a month. When some timbers are allocated to one chamber, the allocated chamber should be used (eq. 9). Eq. 10 dictates a binary variable for chamber usage, where R_{ik} = 1 if the chamber is used, and otherwise R_{ik} = 0.

Results and Discussions

In this section, a case study using the maximum monthly supply form sawmill is used. The numerical example is given to illustrate the application of the model. Table 1 shows the sawmill's capacity and Table 2 shows the sawmill's output for each timber specification.

Based on the historical data, the maximum monthly supply from sawmill to kiln dry are 5,025 m^3 for sawmill A and 3,015 m^3 for sawmill B. The cost of transportation from sawmill to kiln dry, the kiln dry cost, and the capacity are shown in Table 3. Table 4 shows the capacity usage coefficient and drying period for each thickness of sawn timber. Holding cost for each m^3 of timber which places on sawmill A are IDR 20,000 and IDR 30,000 for sawmill B.

Table 1. Sawmill capacity of PT X

Sawmill capacity	Sawmill A (S_A)		Sawmill B (S_B)	
Input	250	m^3 Log	150	m^3 Log
% Yield	67	%	67	%
Output	167.5	m^3 per day	100.5	m^3 per day
	5,025	m^3 per month	3,015	m^3 per month
Total sawmill's output		8,040	m^3 per month	

Table 2. Sawmill's output by specification (in m^3)

Sawmill	Sawing Output (m^3)				Total
	T_1	T_2	T_3	T_4	
S_A	100.50	753.75	1,507.50	2,663.25	5,025
S_B	60.30	452.25	904.50	1,597.95	3,015
Total	160.80	1,206.00	2,412.00	4,261.20	8,040

Table 3. Cost of transportation, transformation and KD capacity from sawmill (in IDR per m^3)

KD	Transport cost (IDR per m^3)		Drying cost for 15 days (IDR per m^3)	KD capacity (m^3 per month)
	S_A	S_B		
K_1	20,000		150,000	2,000
K_2	36,000		250,000	1,200
K_3	40,000	30,000	185,000	1,000
K_4		20,000	200,000	1,500

Table 4. Drying period, capacity usage coefficient, and drying cycle

T	Thickness (mm)	Drying period (days)	Capacity usage coefficient	Chamber drying cycle (per month)
t_1	18	7	0.23	4
t_2	25	10	0.33	3
t_3	30 – 36	20	0.67	2
t_4	50 – 56	30	1.00	1

Solving the sawn timber allocation model (eq. 1 – eq. 5) using MS Excel Solver, the optimal total cost is IDR 2,361,342,300.00 for 7,193 m^3 sawn timber processed in the kiln dry and 847 m^3 sawn timber hold in the sawmill. The resulted timber allocation is shown in Table 5. Kiln dry 2 and 3 only process one kind of thickness, while kiln dry 1 and 4 process dry more than one thickness. Since kiln dry 1 and 4 have to process more than one thickness and different thickness (as shown in Table 2) affects drying duration, we need to set the allocation of sawn timber in each available room in kiln dry 1 and 4.

Based on the optimal result in Table 5, we can find the optimal allocation for each chamber at each kiln dry by solving the second model using MS Excel Solver. Kiln dry 1 has 20 chambers, 12 chambers for kiln dry 2, 10 chambers for kiln dry 3, and 15 chambers for kiln dry 4.

Table 5. Optimal timber allocation from sawmill to kiln dry (in m3)

Timber to	K_1	K_2	K_3	K_4	Total (m^3)
t_1S_A	-	-	-		-
t_2S_A	513	-	-		513
t_3S_A	1,508	-	-		1,508
t_4S_A	824	1,200	134		2,158
t_1S_B			-	60	60
t_2S_B			-	452	452
t_3S_B			-	905	905
t_4S_B			866	732	1,598
Total	2,844	1,200	1,000	2,149	7,193

Kiln dry 2 and 3 get allocation for timber with 50 – 56 mm of thickness that needs 30 days for the drying process. This results in one drying cycle in a month. For kiln dry 2 and kiln dry 3, all chambers are used to dry all timber allocated from the sawmill on one drying cycle. Kiln dry 2 processed 1,200 m^3 of timbers and KD 3 processed 1,000 m^3 of timbers. Since there is no thickness difference to be scheduled in kiln dry 2 and kiln dry 3, it is easier to allocate sawn timber to the kiln dries.

A different situation is faced by the kiln dry 1 and kiln dry 4, where KD 1 and KD 4 have to process more than one thickness specification. The optimization process is done using the chamber allocation model. The minimum chamber usage and timber allocation for each chamber for kiln dry 1 and kiln dry 4 are shown in Table 6 and Table 7. The optimization result shows that only 18 out of 20 rooms of kiln dry 1 is used or a 10% reduction in chamber usage. The average room utilization for the 18 rooms is 97.17%. The number of chambers used in KD 4 is 14 out of 15, with average utilization of 96.43%.

The total capacity processed in KD 1 is 2,844 m^3 of timber with various thickness. We also find mixed thickness allocation in one chamber. Kiln dry 4 processed 2,149 m^3 of timber with various thickness in one chamber.

Sensitivity Analysis

A sensitivity analysis is conducted to know the effect of transportation cost, drying cost, and kiln dry capacity to the total cost.

Table 6. Drying allocation in the chamber for kiln dry 1 (in m^3)

Room	T_2	T_3	T_4	R	Timber processed (m^3)	Capacity usage (%)
1	-	-	100	1	100	100
2	228	-	24	1	252	100
3	-	200	-	1	200	100
4	-	200	-	1	200	100
5	-	-	100	1	100	100
6	-	200	-	1	200	100
7	-	-	100	1	100	100
8	285	10	-	1	295	100
9	-	-	100	1	100	100
10	-	-	-	0	-	-
11	-	-	100	1	100	100
12	-	-	100	1	100	100
13	-	200	-	1	200	100
14	-	200	-	1	200	100
15	-	200	-	1	200	100
16	-	200	-	1	200	100
17	-	98	-	1	98	49
18	-	-	-	0	-	-
19	-	-	100	1	100	100
20	-	-	100	1	100	100
Total (m^3)	513	1,508	824	18	2,844	

The sensitivity analysis result shows that the total cost increases as the transportation and drying cost increase, as shown in Table 8. Both costs are reduced by up to 20% and increased up to 25% of the current data. Table 8 shows that the transportation cost and drying cost affect the total cost. However, the drying cost has a more significant effect on the total cost compared to the transportation cost. The total cost increases up to 2% when the transportation cost 25% higher than the current cost. The drying cost has a more significant effect because the total cost increases by 25% when the drying cost is increased by 25%. The sensitivity analysis shows that the company should consider the drying cost more than the transportation cost because increasing a small percentage of drying cost result in almost the same percentage increase in the total cost. Since the drying cost is significantly sensitive to the total cost, it means that the company can reduce the cost by trying to reduce the drying cost in their own facilities or to get lower cost from outsourced kiln dry companies. The effect of transportation cost reduction is small. Therefore, the company does not need to reduce the transportation cost unless the company cannot reduce its drying cost.

Other parameters used in performing sensitivity analysis are KD capacities. In a real situation, this parameter dynamic depends on subcontractor's support and external factors that are unpredictable, such as chamber maintenance schedule or changing of drying periods. Scenarios performed and the result of KD's capacity changes are shown in the appendix. The KD capacity is reduced by up to 20% and increased up to 20%. The result shows that internal KD capacity change does not affect the total cost per m^3 and the external capacity change affects the total cost per m^3 up to 5%. The effect of the capacity change is higher than the effect of transportation cost, but it is less than the effect of drying cost. Therefore, it is better for the company to put more effort to reduce the drying cost compared to the transportation cost or to increase kiln dry capacity.

Table 7. Drying allocation in the chamber for kiln dry 4 (in m³)

Room	T_1	T_2	T_3	T_4	R	Timber processed (m³)	Capacity usage (%)
1	-	152	99	-	1	251	100
2	60	-	105	32	1	198	100
3	-	-	200	-	1	200	100
4	-	300	-	-	1	300	100
5	-	-	200	-	1	200	100
6	-	-	101	-	1	101	50
7	-	-	-	100	1	100	100
8	-	-	-	100	1	100	100
9	-	-	-	100	1	100	100
10	-	-	-	100	1	100	100
11	-	-	-	100	1	100	100
12	-	-	-	100	1	100	100
13	-	-	-	100	1	100	100
14	-	-	-	-	0	-	-
15	-	-	200	-	1	200	100
Total (m³)	60	452	905	732	14	2,149	

Table 8. Sensitivity analysis of transportation & drying cost

		Drying Cost									
		Down 20%	Down 15%	Down 10%	Down 5%	Current	Up 5%	Up 10%	Up 15%	Up 20%	Up 25%
Transportation Cost	Down 20%	-20%	-15%	-11%	-6%	-1%	3%	8%	12%	17%	21%
	Down 15%	-19%	-15%	-11%	-6%	-1%	3%	8%	13%	17%	22%
	Down 10%	-19%	-15%	-10%	-5%	-1%	4%	8%	13%	18%	22%
	Down 5%	-19%	-14%	-10%	-5%	0%	4%	9%	13%	18%	23%
	Current	-18%	-14%	-9%	-5%	0%	5%	9%	14%	18%	23%
	Up 5%	-18%	-13%	-9%	-4%	0%	5%	10%	14%	19%	23%
	Up 10%	-18%	-13%	-9%	-4%	1%	5%	10%	15%	19%	24%
	Up 15%	-17%	-13%	-8%	-3%	1%	6%	10%	15%	19%	24%
	Up 20%	-17%	-12%	-8%	-3%	1%	6%	11%	15%	20%	24%
	Up 25%	-17%	-12%	-8%	-3%	2%	6%	11%	16%	20%	25%

Conclusions

This paper proposes two different models to minimize the total cost of dry timber preparation for the finishing operations. The first model provides timber allocation for all KD facilities with the minimum cost of transportation from sawmill to kiln dry, minimum drying cost at kiln dry, and minimum holding cost at the sawmill. The allocation results from model one are used in the second model to plan the chamber used at each KD. The first optimal solution results in free chambers in KD 1 and KD 4 even though there is timber that is not sent to the kiln dry. Sensitivity analysis is performed for the cost of transportation and kiln dry's capacity parameters to show the change of the current solution. Both parameters are dynamically changing in real condition and can be prepared to adjust the value in the model to find a new optimal solution. Further research should consider optimal chamber and kiln dry performance with minimum cost and using a stochastic approach instead of the deterministic one.

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