Jurnal Ilmu Kehutanan
https://jurnal.ugm.ac.id/v3/jik/
ISSN: 2477-3751 (online); 0126-4451 (print)

The Effect of Road Conditions on *Acacia mangium* Timber Hauling Performance

(Pengaruh Kondisi Jalan Angkutan Kayu Acacia mangium terhadap Produktivitas Pengangkutan Kayu)

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RESEARCH ARTICLE

DOI: 10.22146/jik.v17i1.5288

MANUSCRIPT:
Submitted : 9 August 2022
Revised : 30 January 2023
Accepted : 21 February 2023

KEYWORD
Cost, Productivity, Road Conditions, Soil Damage, Timber Hauling

ABSTRACT

The quality of timber could be affected by timber hauling, primarily when it remained in the forest and became vulnerable to pests and fungi attacks. Additionally, road conditions could also influence the slickness of hauling. Therefore, this study aimed to identify the effect of road conditions on hauling performance, cost, and soil deterioration. This research analyzed four types of road conditions in Acacia mangium plantations in West Java and Banten, including dry, wet, uphill, and downhill roads. The results indicated that the average hauling performance of 6.604 m^3km/hour on the uphill road was the least among all road types. The uphill soil road had the highest average hauling cost of 30,685 IDR/m^3km and the deepest average rut of 17.503 cm compared to others. These results would provide better information on low-cost and environmentally friendly timber hauling productivity.

KATA KUNCI
Biaya, produktivitas, kondisi jalan, kerusakan tanah, pengangkutan kayu.

INTISARI

Pengangkutan kayu memiliki perngaruh terhadap kualitas kayu, terutama kayu yang belum dikeluarkan dari hutan, dan berpotensi terserang hama dan jamur. Kondisi jalan angkut berpengaruh terhadap kelancaran pengangkutan kayu. Penelitian ini dilakukan pada empat jenis kondisi jalan pengangkutan kayu hutan tanaman Acacia mangium di Jawa Barat dan Banten, yaitu jalan tanah kering, tanah basah, jalan tanah menanjak, dan jalan tanah menurun. Kami mengidentifikasi pengaruh kondisi jalan angkutan kayu pada produktivitas, biaya angkutan dan efek negatif terhadap tanah. Hasil penelitian menunjukkan bahwa rata-rata prestasi kerja pengangkutan kayu Acacia mangium di jalan tanah menanjak kurang efektif dan efisien dibandingkan ketiga kondisi jalan lainnya yaitu 6,604 m^3km/jam. Jalan tanah menanjak juga mempunyai biaya rata-rata pengangkutan paling tinggi yaitu sebesar Rp 30.685/m^3km dan rata-rata kerusakan tanah paling dalam yaitu sebesar 17,503 cm dibandingkan dengan jenis jalan lainnya. Hasil studi ini akan berkontribusi terhadap informasi mengenai produktivitas pengangkutan kayu melalui pengangkutan kayu berbiaya rendah tanpa merusak jalan tanah.

Introduction

Hauling activities became crucial elements in the timber supply chain that started after felling and skidding in the forest to the industry (Karagiannis et al. 2012). The hauling trucks transported harvested timbers from the temporary log yards to larger log yards or directly to the industries. This process required high vigilance to prevent the timbers from falling to the ground, reducing their quality (Yuniawati et al. 2015). Trucks became commonly used for timber hauling in dryland forest plantations because they could transport timbers in large quantities and traverse various road conditions, such as asphalt, non-asphalt, rocky, uphill, and downhill. In addition, modifying truck trailers to suit the transported goods was relatively easy, and workshops for truck maintenance were easily accessible and available (Johannes et al. 2018).

Timber-hauling trucks often travel on non-asphalt roads because the locations of temporary log yards are within the forest. Road conditions and truck types determine the effective payload. The location, topography, soils, climate, size of the harvesting block, size of timbers, road conditions, distance, and costs determine the performance of timber hauling (Simangunsong 2018). Akay et al. (2021) suggested that roads are a primary infrastructure providing sustainable access to forest areas. Road construction should conform to adequate technical standards to properly run its crucial function. The overall hauling performance depends on hauling time, distance, truck speed, timber volume, topography, and area conditions (Norizah et al. 2016; Mousavi and Naghdi 2013).

Timber hauling activities had a significant proportion of the operational cost (Acuña 2017). They accounted for approximately ±30% of the total timber harvesting cost (Kuloglu et al. 2019), nfluencing the timber hauling method and technique (Simangunsong 2018). Timber harvesting could be financially profitable. For example, timber harvesting in Kentucky, USA, contributed around $5 billion per hectare (Niman et al. 2018). However, timber harvesting could also damage soil surface through compaction and erosion (Bigelow et al. 2018; Visser et al. 2018). Therefore, efficient log hauling is crucial to ensure sustainable benefits from timber harvesting for individual landowners and local communities and reduce the impact on environmental damage.

The hauling roads of Perum Perhutani, a state-owned forestry company, were unpaved and had safety concerns, especially during the rainy season. These conditions led to delays in timber hauling and a decrease in timber quality, which affected the selling price (Yuniawati & Dulsalam 2014). This research aimed to analyze the effects of road types on the work performance and cost of timber hauling activities in Perum Perhutani West Java. This research also looked at the soil condition impacted by hauling activities on four road types. The results could become inputs for Perum Perhutani in formulating policies on road maintenance for efficient and environmentally friendly timber hauling.

Materials and Methods

Materials

This research took place at the Maribaya Forest Management Resort (RPH), Parung Panjang Forest Management Unit Section (BKPH), Bogor Forest Management Unit (KPH), in Perum Perhutani Unit III West Java and Banten. This research used *Acacia mangium* timber, a distance meter, a timer, a Colt Diesel 100 PS truck, a digital camera, and writing instruments.

Procedures

The procedures carried out in this study were as follows.

Table 1. Hauling road characteristics in RPH Maribaya, BKPH Parung, KPH Bogor

Road types	Description	Road slope (%)	Average	
			Road width (m)	Road length (m)
Unpaved/Dry road*	Most hauling road surface conditions had no asphalt, only the ground surface. Roads were dry when not exposed to rainwater	9-15	3-4	6.5
Wet road	The road surface was wet soil due to exposure to rainwater	16-25	3-4	5.3
Uphill road	The road surface was soil with an uphill slope	16-25	3-4	4.2
Downhill road	The road surface was soil with a downhill slope	9-15	3-4	4.2

Remarks: *served as control

1. The logging compartment for timber hauling were purposively selected based on the purpose of the study.
2. In the selected logging compartment, four hauling road conditions (unpaved, wet, uphill, and downhill roads) were identified and characterized (Table 1).
3. Hauling was carried out on the four road types using the same type of truck with ten repetitions and recording on timber volume, hauling time, and distance traveled by trucks.
4. The depth was measured on each road with ten repetitions to determine road damage.

Data Analysis

The data analysis included comparing performance, costs, and road damage of timber hauling activities on four road types. The analysis used Analysis of Variance (ANOVA) to compare hauling activity performance on four road types and multiple regression to analyze the effect of volume, distance, and time of timber hauling on the hauling performance. The analysis also used simple regression to analyze the effect of timber hauling performance on the hauling cost and the effect of soil damage (rut depth) on timber hauling performance. Below are the equations used in the data analysis.

1. Timber hauling performance (Dulsalam & Suzanto 1997):

$$P = \frac{V \times J}{W} \quad \text{......(1)}$$

with description: P = performance (m^3km/hour); V = hauled timber volume (m^3); J = hauling distance (km); W = travel time (hours).

2. Hauling cost (Suhartana & Yuniawati 2006):

$$BP = \frac{BU}{P} \quad \text{......(2)}$$

with description: BP = hauling cost (Rp/m^3); BU = operation cost (Rp/hour); P = timber hauling performance (m^3/hour).

3. ANOVA determined the differences in timber hauling performance on four road types. The hypothesis and basis for decision rules are as follows.
   a. Hypotheses:
      - Ha: There are differences in average timber hauling performance on the four road types.
      - Ho: There is no difference in the average timber hauling performance on the four road types.
   b. Decision rule (Purnomo 2016):
      - If the p-value of significance (sig.) <0.05, Ho is rejected, meaning that the average timber hauling performance on the four road types has a difference.
      - If the p-value of significance (sig.) >0.05, Ho is accepted, meaning that the average timber hauling performance on the four road types has no difference.
4. A multiple linear regression analyzed the effect of volume, hauling time, and distance on timber

hauling performance using SPSS 25.0 software (Janie 2012):

Regression model:

$$Y = a + b_1X_1 + b_2X_2 + ...+b_nX_n \quad ....(3)$$

with description: Y = dependent variable; a = intercept; $b_{1,2,n}$ = regression coeffiecient; $X_{1,2,n}$ = independent variables;

a. Hypotheses:
   - Ha: Timber volume, hauling time, and distance have a significant effect on timber hauling performance.
   - Ho: Timber volume, hauling time, and distance have no significant effect on timber hauling performance.

b. Decision rule (Purnomo 2016):
   - If the significance value (sig.) <0.05, Ho is rejected, meaning that timber volume, hauling time, and distance have a significant effect on timber hauling performance.
   - If the significance value (sig.) >0.05, Ho is accepted, meaning that timber volume, hauling time, and distance have no significant effect on timber hauling performance.

5. A simple linear regression analysis was performed to determine the effect of timber hauling performance on the hauling cost of *Acacia mangium* (regression 1) and the effect of soil damage (rut depth) on timber hauling performance (Regression 2).

   a. Equation model:

   $$Y = a + b_1X_1 \quad ....(4)$$

   Description: Y = dependent variable (regression 1 = timber hauling cost; regression 2 = timber hauling performance); a = intercept; b_1 = regression coefficient; X_1 = independent variable (timber hauling performance, rut depth)

   Hypotheses:
   - Regression 1:
     - Ha: There is an effect of timber hauling performance on hauling cost.
     - Ho: There is no effect of timber hauling performance on hauling cost.
   - Regression 2:
     - Ha: There is an effect of soil damage (rut depth) on timber hauling performance.
     - Ho: There is no effect of soil damage (rut depth) on timber hauling performance.

   b. Decision rule (Purnomo 2016):
   - Regression 1:
     - If the sig. <0.05, Ho is rejected, meaning that there is an effect of timber hauling work performance on hauling cost.
     - If the sig. >0.05, Ho is accepted, meaning that there is no effect of timber hauling work performance on hauling cost.
   - Regression 2:
     - If the sig. <0.05, Ho is rejected, meaning that there is an effect of soil damage (rut depth) on timber hauling performance.
     - If the sig. >0.05, Ho is accepted, meaning that there is no significant effect of soil damage (rut depth) on timber hauling performance.

Results and Discussion

Hauling Performance

The average timber hauling performance of *Acacia mangium* varied across four road types (Table 2). The dry road, which served as the control, yielded better average timber hauling performance than others. The uphill road had a lower average performance of 6.604/14.388 x 100% = 45.90% due to a slower average hauling time of 1.531 hours for a distance of 4.2 km and a timber volume of 2.406 m^3. The downhill road also had a lower average of 11.028 m^3km/h compared to the dry road due to slippery roads (clay loam soil), ruts, and tracks of other vehicles, demanding extra caution from the drivers. Road characteristics, hauling distance, properties of hauled material, operator skills, and the weather could influence the hauling efficiency, cost, and environmental damage (Akay and Demir 2022; Anttila et al. 2022).

Field observations showed that truck drivers tended to increase engine power, leading to a longer travel time on the uphill road. Hilly terrain required skillful operators (Setiawati et al. 2013) who could immediately shift to a lower gear when the engine started to struggle on a higher gear and prevented the truck from rolling back due to delays in shifting to a lower gear. Lower gear was also required for the downhill road because relying solely on brakes while driving in higher gear was dangerous and could cause adverse outcomes. Heavy equipment productivity depended on topography, operator skills, operation, and equipment maintenance in the field and differed from the ideal condition.

Research on hauling roads should also examine road grade or slope in percentage (%) because it directly relates to the hauling equipment's ability to brake and overcome the uphill road. Generally, the maximum hauling road grade ranges from 10-8%, but it is safe to have a maximum of 8% on uphill or downhill roads (Sitangger et al. 2019).

The one-way ANOVA indicated that the average timber hauling performance among four road types differed significantly with a p-value <0.05 (Table 3). Therefore, road conditions and slope affected the average timber hauling performance. Similar research on pine timber hauling in KPH Sukabumi revealed that the higher the slope percentage, the lower the timber hauling performance (Yuniawati & Dulsalam 2014).

A multiple regression analyzed the effect of

Table 2. The average timber hauling work performance of *Acacia mangium*

Road types	Statistics	Effective hauling time (hours)	Timber volume (m^3)	Travel distance (km)	Work performance (m^3km/hour)
Dry road*	Total	10.959	24.255	65	143.876
	Average	1.096	2.426	6.5	14.388
	Minimum	1.072	2.315	6.5	13.427
	Maximum	1.121	2.576	6.5	15.178
Wet road	Total	12.707	23.852	53	99.959
	Average	1.271	2.385	5.3	9.959
	Minimum	1.190	2.234	5.3	9.513
	Maximum	1.386	2.1523	5.3	10.648
Uphill road	Total	15.308	24.055	42	66.043
	Average	1.531	2.406	4.2	6.604
	Minimum	1.46	2.321	4.2	6.185
	Maximum	1.58	2.536	4.2	6.997
Downhill road	Total	9.146	23.997	42	110.282
	Average	0.915	2.400	4.2	11.028
	Minimum	0.889	2.311	4.2	10.409
	Maximum	0.942	2.489	4.2	11.529

Remarks: * served as control

Table 3. ANOVA for timber hauling performance on four road types

	SS	DF	MS	F	p Sig.
Between groups	308612361.675	3	102870787.225	581.305	.000
With groups	6370745.300	36	176965.147		
Total	314983106.975	39			

Remarks: SS= Sum of Squares, DF = Degree of Freedom, MS = Mean Square

Table 4. The effect of timber volume, hauling distance, and time to timber hauling performance

Model	R	R^2	Adjusted R^2	Standard error calculation
1	.986[a]	.971	.969	500.451

Remarks: [a]Dependent variable = timber hauling performance

Table 5. ANOVA for the effect of timber volume, hauling distance, and time to timber hauling performance

Model		SS	DF	MS	F	p Sig.
1	Regression	305966877.449	3	101988959.150	407.222	.000
	Residual	9016229.526	36	250450.820		
	Total	314983106.975	39			

Remarks: SS= Sum of Squares, DF = Degree of Freedom, MS = Mean Square

Table 6. The regression coefficients of timber volume, hauling time, and distance for timber hauling performance

Model[a]		Unstandardized coefficient		Standardized coefficient	T	p Sig.
		B	SE	Beta		
1	Constant	9338.709	804.386		11.610	.000
	Timber volume	.049	.145	.010	.337	.000
	Hauling time	-7.411	.350	-.609	-21.163	.000
	Travel distance	-1972.858	88.975	-.668	-22.173	.000

Remarks: [a]Dependent variable: Hauling performance, SE = Standard Error

timber volume, hauling time, and distance on average timber hauling performance (Tables 4-6). Meanwhile, Table 4 showed a value of 0.969 for the adjusted R^2, meaning that the variability in timber volume, time, and distance explained 96.9% of the variability in timber hauling performance, while other factors explained the remaining 100%-96.9% = 3.1%. Table 5 indicated a significant probability value (p-value <0.05), meaning the multiple regression model could fit the timber volume, hauling time, and distance data and predict the average timber hauling performance.

The regression equation resulting from the analyses was $Y = 9338.709 + 0.049X_1 - 7.411X_2 - 1972.858X_3$ (Table 6). An increase in the hauled timber volume would improve timber hauling performance. However, an increase in hauling time (one hour) and distance (one kilometer) would decrease the hauling performance by 7.411 m^3km/hour and 1972.858 m^3 km/hour, respectively. The higher the hauling time and distance, the lower the hauling performance because their regression coefficients were negative. Similar research also indicated a relatively strong negative correlation between hauling productivity and distance, ranging from r = 0.47 to r = 0.68 (Allman et al. 2021).

Timber Hauling Cost

Timber is a heavyweight material, and timber hauling is challenging, especially when faced with a steep slope and long travel distance (Endom & Soenarno 2015). The average tree volume, timber hauling distance, growing stock per hectare, and species composition could influence the hauling cost (Bespalova et al. 2019). The observation indicated that the average hauling cost of *Acacia mangium* on an uphill road type was more expensive than others (Table 7). The topographical grade could increase fuel consumption. Loaded trucks passing through the

Table 7. The average timber hauling cost of *Acacia mangium* in four road types

Road types	Statistics	Performance (m^3 km/hours)	Hauling cost (Rp/m^3 km)
Dry road*	Total	143.876	140.861
	Average	14.388	14.086
	Minimum	13.427	13.335
	Maximum	15.178	15.074
Wet road	Total	99.587	203.499
	Average	9.959	20.350
	Minimum	9.513	19.008
	Maximum	10.648	21.276
Uphill road	Total	66.044	306.854
	Average	6.604	30.685
	Minimum	6.185	28.926
	Maximum	6.997	32.724
Downhill road	Total	110.284	183.806
	Average	11.028	18.381
	Minimum	10.409	17.460
	Maximum	11.592	19.444

uphill road require 2.5 times more fuel than the downhill road (Pandur et al. 2021; Väätäinen et al. 2021).

This research showed that average hauling performance affected average hauling cost, as previously reported by (Suhartana & Yuniawati 2016; Norizah et al. 2016). Improving hauling performance could minimize hauling costs. Tables 8-10 analyzed the effect of timber hauling performance on hauling cost. Table 8 indicated that the adjusted R^2 value was 0.933, meaning that the variability in hauling performance explained 93.3% of the variability in timber hauling cost, while other factors explained the remaining 100% - 3.3% = 6.7%. Table 9 indicated a significant probability value (p-value <0.05), meaning the multiple regression model could fit the hauling performance data and predict the hauling cost. The regression equation resulting from the analysis was Y = 43.110 - 0.002X1 (Table 10).

A unit (one m^3km/hour) increase in timber hauling performance could reduce Rp 0.002/m^3km of hauling costs. A negative coefficient signified an inverse relationship between timber hauling performance and hauling cost, with higher

Table 8. The effect of hauling performance on hauling cost

Model[a]	R	R^2	Adjusted R^2	Standard error calculation
1	.967[a]	.934	.933	1.617603

Remarks: [a]Dependent variable= Hauling cost

Table 9. ANOVA for the effect of hauling performance on hauling cost

	Model[a]	SS	DF	MS	F	p Sig.
1	Regression	1413.854	3	1413.854	540.332	.000
	Residual	99.432	36	2.617		
	Total	1513.286	39			

Remarks: SS= Sum of Squares, DF = Degree of Freedom, MS = Mean Square

Table 10. The regression coefficients of hauling performance for hauling cost

	Model[a]	Unstandardized coefficient		Standardized coefficient	T	p Sig.
		B	SE	Beta		
1	Constant	43.110	.990		43.539	.000
	Hauling performance	-.002	.000	-.967	-23.245	.000

Remarks: [a]Dependent variable= hauling cost, SE = Standard Error performance leading to lower production costs. For this reason, productivity should become a measure of optimization (Pasch & Uludag 2018; Baxter 2016). The challenges for timber hauling activities have increased because of the need for more truck drivers, longer hauling distances, higher hauling costs, poor hauling road conditions, lack of insurance, and the timing for completing harvesting activities (Conrad 2018; Koirala et al. 2017). Reducing timber harvesting costs, which accounted for 60% of the total forest management costs, could increase the overall economic efficiency of forest management (Bont et al. 2022).

Soil Damage on Hauling Roads

Timber hauling activities could damage soil on the hauling roads in the form of ruts created by the friction between the truck tires and road surfaces (Table 11). In addition, timber harvesting activities caused erosion and removed humus, organic matter content, and nutrients, reducing soil fertility. Soil disturbance also degraded soil properties, such as compaction, reduced infiltration, and decreased macroporosity (Haas et al. 2020; Eroğlu et al. 2016; Solgi & Najafi 2014).

Table 11 indicated that the ruts on the uphill road were deeper than on other road types, with an average of 17.503 cm and a difference of 15.28 cm from the dry road. Continuous friction between truck tires and the ground surface created ruts. On the uphill road, friction occurred more frequently for an additional grip of tires on the road surface (traction). These ruts and road damage could hinder timber hauling activities, reduce driving safety, create traffic congestion, and accelerate damage to vehicle parts (Safitra et al. 2019).

The average rut depth on roads with an uphill slope of 16-25% was 17.503 cm. This value was lower than Yuniawati & Suhartana (2015) on a slope of 18% with an average rut depth of 19.42 cm. Their research location had a clay loam soil texture that became slippery when wet, causing truck obstacles. The friction between vehicle tires and the road surface during hauling activities could directly affect and change soil properties Cudzik et al. (2017). Adding branch cuttings, such as brush base, of 15 and 20 kg/m^2 along the route could reduce soil disturbances by harvesting machines and create shallow ruts of 3.8 cm (Poltorak et al. 2018).

There were differences in rut depth in four *Acacia*

Table 11. The average rut depth due to *Acacia mangium* timber hauling

Road types	Statistics	Rut depth (cm)
Dry road*	Total	22.23
	Average	2.223
	Minimum	1.75
	Maximum	2.69
Wet road	Total	106.61
	Average	10.661
	Minimum	9.34
	Maximum	11.54
Uphill road	Total	175.03
	Average	17.503
	Minimum	15.25
	Maximum	19.33
Downhill road	Total	39.39
	Average	3.939
	Minimum	3.73
	Maximum	4.15

Table 12. ANOVA of rut depth on four timber hauling road types

	SS	DF	MS	F	p Sig.
Between groups	1459.008	3	486.336	756.767	.000
With groups	2.,135	36	.643		
Total	1482.144	39			

Remarks: SS= Sum of Squares, DF = Degree of Freedom, MS = Mean Square

Table 13. The effect of rut depth on timber hauling performance

Model	R	R^2	Adjusted R^2	Standard error calculation
1	.924[a]	.853	.849	1104.354

Remarks: [a]Dependent variable= Hauling performance

Table 14. ANOVA for the effect of rut depth on hauling performance

Model[a]		Squared sum	Free degree	Squared average	F	p Sig.
1	Regression	268638412.810	1	268638412.810	220.268	.000
	Residual	46344694.165	38	1219597.215		
	Total	314983106.975	39			

Remarks: [a]Dependent variable = Hauling performance

Table 15. The regression coefficients of rut depth for timber hauling performance

Model[a]		Unstandardized coefficient		Standardized coefficient	T	p Sig.
		B	SE	Beta		
1	Constant	14148.216	301.806		46.878	.000
	Rut depth	-425.735	28.686	-.924	-14.841	.000

Remarks: [a]Dependent variable: Hauling performance

mangium timber hauling road types with p-value <0.05 (Table 12). The adjusted R^2 was 0.849, meaning that the variation in rut depth explained 84.9% of the variation in hauling performance, while other variables explained the remaining 15.1% (Table 13). Table 14 indicated a significant probability value (p-value <0.05), meaning the regression model could fit the rut depth data and predict the hauling performance.

The regression equation resulting from the analysis was $Y = 14148.216 - 425.735X_1$ (Table 15). This equation indicated that a unit of rut depth (one cm) could decrease the timber hauling performance by 425.735 m^3km/hour. Road damage would significantly reduce the vehicle's speed (Yusra et al. 2018), Therefore, creating adequate infrastructure will not only improve the accessibility and timber and other forest resources utilization but also contribute to the development of sustainable forest management (Mokhirev et al. 2021).

Conclusion

This research indicated that hauling road types affected average hauling performance. Based on the results, the uphill road had the lowest average timber hauling performance compared to others because the truck drivers needed more time trying to generate more traction to navigate the uphill road, resulting in higher hauling costs. The continuous movement of truck tires when passing the uphill road also caused damage to the soil surface, forming ruts and affecting timber hauling performance.

Acknowledgments

The authors are grateful to the Perum Perhutani in West Java and Banten, especially the Bogor Forest Management Unit, for their assistance in data collection, which significantly contributed to this research.

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