E-ISSN: 2528-388X
P-ISSN: 0213-762X

INERSIA
Vol.21, No.1, May 2025

Mode Choice and Spatial Distribution of Coal Transport in Jambi, Indonesia

Nurman Nugroho*, Sigit Priyanto, Bambang Triatmodjo

Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

Keywords:
Generalized cost
Mode choice
Multinomial logit
Spatial

ABSTRACT

Coal is an important commodity for Jambi Province. Based on data from the Central Bureau of Statistics, in the first quarter of 2022, the value of coal exports reached 10.75% of the total export value. Apart from being exported, coal commodity is also used for domestic purposes. The transport used at this time is only through public roads. The use of these routes results in many problems such as traffic accidents, congestion, and social conflicts. Therefore, the number of vehicles allowed to pass on public roads is limited. This has resulted in the production target plan not being achieved, only 17.3 million tonnes out of 40 million tonnes in 2022. Hence the need for other routes for transport such as rivers, special roads, and railways. This research is intended to analyse coal transport trips using trucks, barges and railways. This research discusses the closest route, mode selection, and transport costs based on the distance travelled and the travel time of each mode. The search for the closest travel route is done by spatial analysis with Network Analyst on ArcGIS. Mode choice was analysed using the multinomial logit method. Meanwhile, transport costs are calculated based on the principle of generalised cost. Modelling results on the selection of mode, during the rainy season the most efficient mode is barging with a selected probability of 44%, while rail 28% and transport by truck 27%. During the dry season, the probability of transport by railway is 93%, barge 4% and truck 3%. The results indicate that the most efficient mode during the rainy season is barging and during the dry season transport by railway.

1. Introduction

As the demand for coal in the global market continues to increase, coal mining capacity has increased rapidly. This was marked by the establishment of a coal production target plan of 40 million tonnes in 2022 by the Ministry of Energy and Mineral Resources for Jambi Province. However, according to the Ministry of Energy and Mineral Resources, the target plan was not achieved. Coal production in Jambi Province was only able to reach 17.3 million tonnes in 2022. The failure to achieve the target is caused by problems that occur in the transport or distribution process. During this time, the transport of coal from mining areas only relies on public roads. Coal distribution through public roads often causes problems such as accidents involving coal transport vehicles and other road user vehicles. Severe congestion, pavement damage and social conflict are also other consequences of transporting coal via public roads. This means that coal transport in Jambi Province does not meet the criteria for effectiveness and efficiency as stated in the National Transport System (SISTRANAS). Therefore, the Jambi Provincial Government plans to build a special road for coal transport and build Tenam Port as a supporting infrastructure for the movement of coal commodities. In order to organise effective and efficient coal transport as required in the National Transport System (SISTRANAS), there is a need for a comprehensive analysis of the movement. That is why this research was conducted by modelling coal transport distribution in Jambi Province.

Several studies with various models have been conducted to determine the optimal freight transport journey. Modelling in the aspect of freight transport often uses multinomial logit as its mode choice model. As has been done in previous study [5] who used a multinomial logit model with travel time, travel costs, and climate as determining variables to determine the choosing of crude palm oil (CPO) transport modes. Research with a similar model [9], which determined the modes choice of freight transport on the island of Java using travel costs, waiting time, and reliability as the determining variables. Reference [4] in their research, used the lowest cost concept and [7] used the closest transport network model

*Corresponding author.
E-mail: nurman.nugroho@mail.ugm.ac.id

https://doi.org/10.21831/inersia.v21i1.64336
Received 23th July 2023; Revised 30th May 2025; Accepted 12th June 2025
Available online 13th June 2025

to model coal transportation without any other factors as decision-making parameters by the owner of the goods. This research was conducted with the intention of determining the optimal mode choice based on the optimal generalised cost and the closest travel route [8]. The model used is multinomial logit with travel cost, travel time and climate as determining attributes.

2. Methods

In general, the modelling in this study includes several stages. The research began with spatial modelling, generalised cost analysis, and mode choice modelling. Each modelling and analysis use various software as tools.

2.1 Spatial Modelling

The spatial model is intended to illustrate where the areas that act as generators of travel and destinations for coal transport travel. As in the previous research [5], the spatial-based transportation modelling process is assisted by an ArcGIS software that has been equipped with a special tool for transportation network analysis called Network Analyst [10]. The data required for spatial-based transport modelling include transport networks, administrative boundaries, and other land use information. Details of the data required for spatial-based transport modelling can be seen in Table 1.

2.2 Generalised Cost Analysis

The second stage of modelling in this study was to determine and select the most optimal transport modes based on generalised costs, referring to the opinion expressed by [11]. The generalised cost analysis uses Microsoft Office Excel number crunching software. The generalised cost calculation formula can be written as Equation 1.

$$C_{ij}^{m} = TC_{ij}^{m} + TT_{ij}^{m} VoT + \delta \tag{1}$$

where C_{ij}^{m} is the overall generalised cost characterised by currency units (Rp). TC_{ij}^{m} is the vehicle travel rate per unit distance (Rp/km). Costs incurred based on the length of the journey are expressed by travel time (TT_{ij}^{m}) using time units, as well as the time value of the goods transported (VoT) using currency units per unit time. The other components of travel costs are denoted by δ.

Since time cannot be owned and traded, the value of travel time savings should be introduced [3]. The value of travel time based on savings is represented by a monetary value, whereby savings in travel time in a particular context can be compensated with monetary savings. In the aspect of freight transport known as value of freight travel time saving (VFTTS) can be defined as the monetary value derived from the reduction in units of time required to move goods between two locations [2]. In a previous study, estimating the value of savings with meta-models on freight transport in several countries. The VFTTS value in Indonesia obtained from the study is summarised in Table 2.

2.3 Mode Choice

There are various models that can be used to estimate the best mode choice. The multinomial logit model was chosen to determine the mode of transport in this study. The model has been widely used for modelling passenger and freight transport. Table 3 summarises the data and attributes required in modelling mode choice.

Table 1. Spatial data for modelling

Data	Sources
Inventory of transport networks and infrastructure	Departemen Perhubungan; Departemen Pekerjaan Umum dan Perumahan Rakyat
Mining area	Dinas Energi dan Sumber Daya Mineral Provinsi Jambi;
Regional administration map; Hydrology map; Land use	Badan Informasi Geospasial
Local regulations of transport and land use	Badan Perencanaan dan Pengembangan Daerah Provinsi Jambi; Dinas Perhubungan Provinsi Jambi

Table 2. Value of freight travel time in Indonesia [2]

Route	VoT (USD per tonne/hour)	
	Carriers	Shippers
Road	1.47	0.22
Railway	0.25	0.04
Air	21.16	3.23
Sea	0.17	0.03
Inland Waterway	0.08	0.01

Table 3. Mode choice modelling data and attributes

Data/Attributes	Data Source
Speed	Truck: Observation, Railway: Literature review [6], Barge: Literature review [4]
Distance	Spatial modelling
Travel time	Spatial modelling and calculation
Travel cost	Truck: calculation, Railway: Literature review [9], Barge: calculation
Climate	Balai Wilayah Sungai Sumatera IV

Multinomial logit model can be written as Equation 2.

$$P_n(i|Cn) = \frac{\exp \mathrm{Vi}}{\sum_{j=1}^{n}(\exp \mathrm{V\,j})} \qquad (2)$$

P_n is the probability that alternative i is chosen by individual n in the choice set C_n. The multinomial logit model is used by most studies because it is a simple model. With this consideration, the multinomial logit model was used in this study.

2.4 Modelling Procedures

Broadly speaking, the modelling in this study starts with the preparation of spatial data. Then, a geographic information system (GIS) simulation was conducted using ArcGIS software with transport attributes (vehicle speed, trip limits) as input. The simulation results (output) are in the form of an origin-destination matrices with the closest travel route and its attributes (distance and travel time). With the new travel attributes obtained, the generalised cost of each mode can be calculated to determine the most optimal transport mode. An overview of the modelling procedure can be seen in Figure 1.

3. Result and Discussion

Travel modelling studies usually consider various influencing factors. Factors that are commonly considered for freight transport trips are distance, travel time, freight fares, as well as several other factors. In the aspect of freight transport, sometimes the influence factors are also inherent along with the characteristics of the goods or the characteristics of the transport mode itself. Such as previous research [5], this study on coal transport modelling also considers climatic conditions in addition to the general factors mentioned.

3.1 Travel Cost

The travel costs of each mode are obtained based on vehicle operating cost calculations and literature studies as discussed in the previous chapter. The travel costs of each mode are summarised in Table 4.

Table 4. Travel cost of coal transport

Modes	Max Capacity	Cost (Rp/tonne km)
Truck	15 tons	932
Barge	6.000 - 12.000 tons	24
Railway	50 tons/car	709

3.2 Spatial Distribution of Coal Transport

As seen in Figure 2, the trips originated from 100 coal mine sites and were destined to three ports. During the rainy season, the entire port is assumed to be able to service coal shipments. Meanwhile, during the dry season, there are only two ports that can handle shipments.

Coal transport by trucks over public road

Figure 3**Figure** illustrates, the most common shortest travel route from the mine is to Tenam Port. A total of 77 out of 100 shortest travel routes are to Tenam Port. The shortest travel route to the special terminal in Tebing Tinggi is 15 out of 100 routes. The other part is a route with the destination of Talang Duku Port, namely 8 routes. The largest variation of shortest routes is in the range of mileage from 50 km to 100 km, this is because most of the locations of coal mines are relatively close to one of the ports.

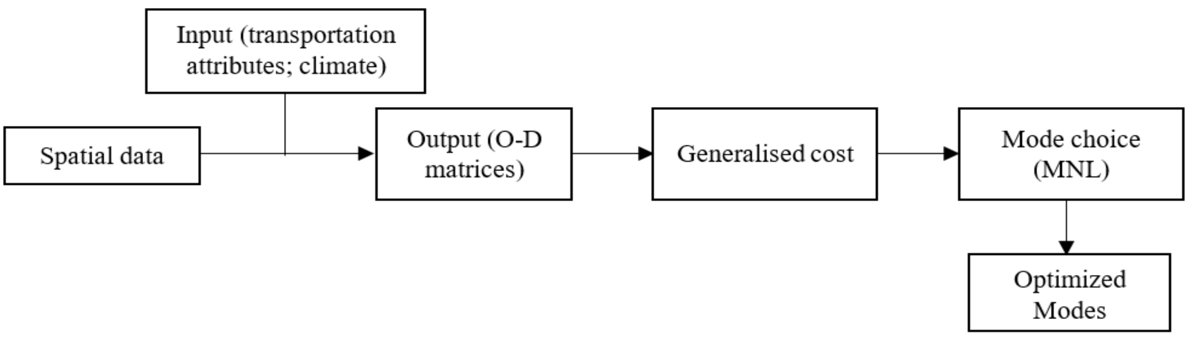


Figure 1. Coal transport modelling flow chart

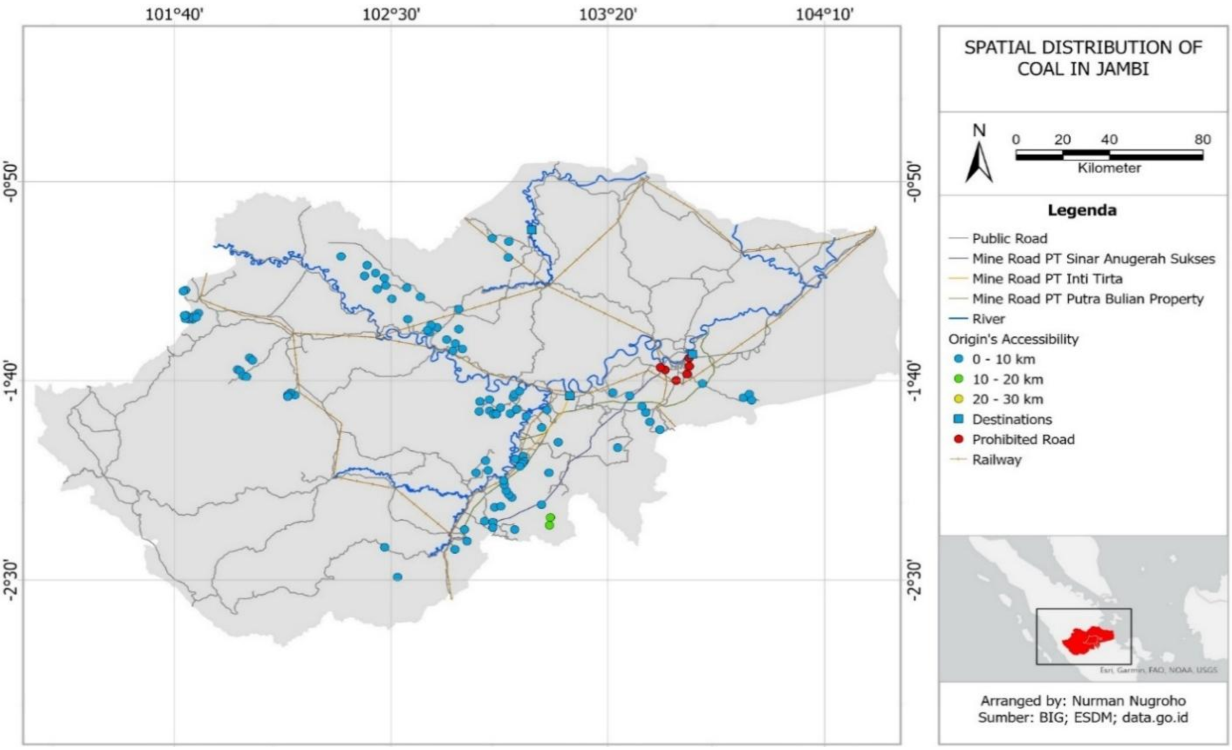
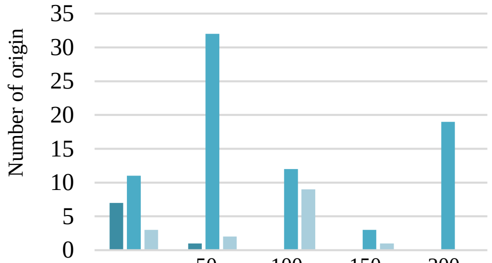
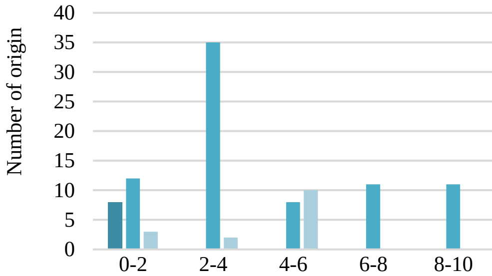


Figure 2. Coal transport modelling flow chart



Distance (km)	0-50	50-100	100-150	150-200	200-250
Talang Duku	7	1	0	0	0
Tenam	11	32	12	3	19
Tebing Tinggi	3	2	9	1	0

Figure 3. Travel distance of truck by public road (rainy season)



Travel time (hours)	0-2	2-4	4-6	6-8	8-10
Talang Duku	8	0	0	0	0
Tenam	12	35	8	11	11
Tebing Tinggi	3	2	10	0	0

Figure 4. Travel time of truck by public road (rainy season)

As shown in Figure 4, most of the trips with the shortest travel time are routes to Tenam Port. A total of 68 out of 100 routes travelled with a travel time between 0-10 hours. A total of 15 out of 100 routes travelled to Tebing Tinggi special terminal with a travel time of 0-6 hours. Another five routes went to Talang Duku Port with a travel time between 0-2 hours.

A total of 55 mining areas are closer to Talang Duku Port, while the other 44 areas are closer to the terminal in Tebing Tinggi during the dry season. The travelling distance in Figure 5 and travelling time in Figure 6 by the shortest route to Talang Duku Port is mostly between 100 km and 200 km and the travelling time is 4 hours to 8 hours. The routes with terminal destinations in Tebing Tinggi are mostly spread over distances of 100-150 km and 200-250 km and the travel times are spread over the ranges of 4-6 hours and 8-10 hours.

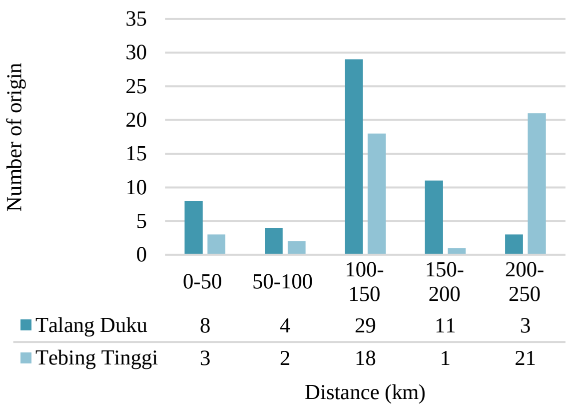


Figure 5. Travel distance of truck by public road (dry season)

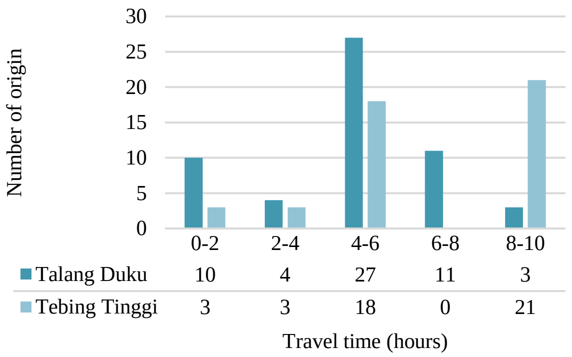


Figure 6. Travel time of truck by public road (dry season)

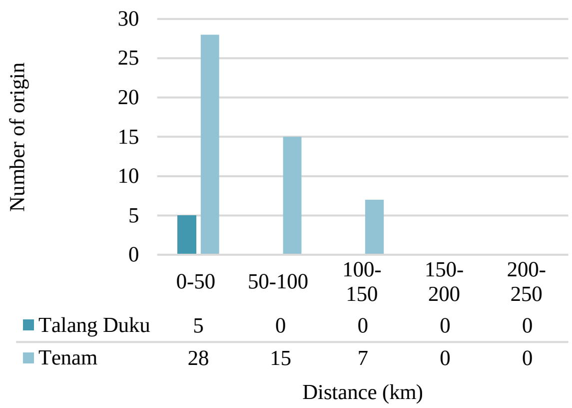


Figure 7. Travel distance of truck by mine road (rainy season)

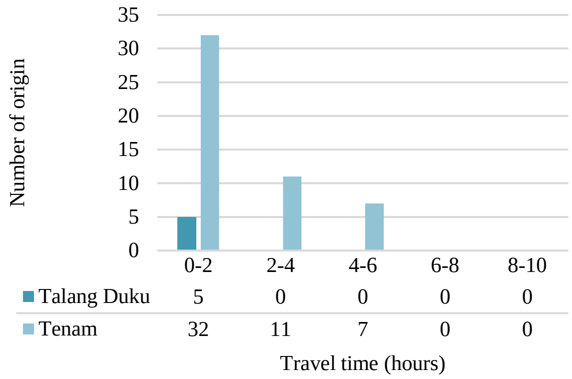


Figure 8. Travel time of truck by mine road (rainy season)

Coal transport by trucks over mine road

As Figure shows, Tenam Port is the closest to 33 mine sites that are directly connected to the PT Inti Tirta Special Road with a distance between 0 km and 100 km. A total of 18 mine sites are adjacent to the PT Sinar Anugerah Sukses Dedicated Terminal with a route distance of 0 km to 100 km, while 4 other mine sites are adjacent to Tenam Port which is connected to the PT Putra Bulian Properti Dedicated Road with a route distance of 0 km to 50 km.

Based on the Figure 8, the transport of coal by truck through mine roads during the rainy season, obtained 32 trip origins that go to Tenam Port with a travel time range of 0-2 hours. There are 11 trip origins to the port in the 2-4 hours travel time range and there are 7 trip origins that require travel time from 4 to 6 hours.

The travel distances generated from the origin-destination analysis show that most of the routes with the destination of Talang Duku Port are between 100 km and 150 km and the average distance of all routes is 109 km. The distribution of truck travel distances via special roads during the dry season can be seen in Figure 9.

As illustrated in the travel time distribution in Figure 10, most routes were travelled for 4 hours to 6 hours. The average journey time for trucks travelling on special roads is 4.2 hours.

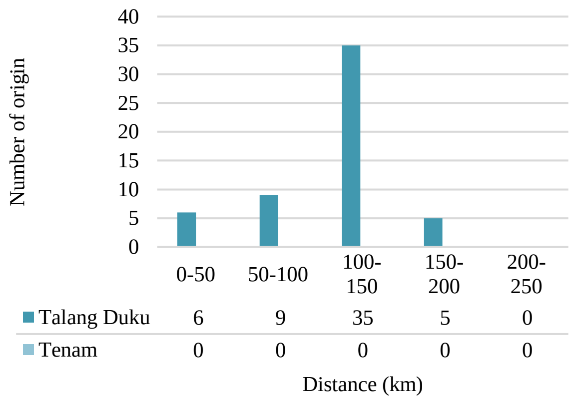
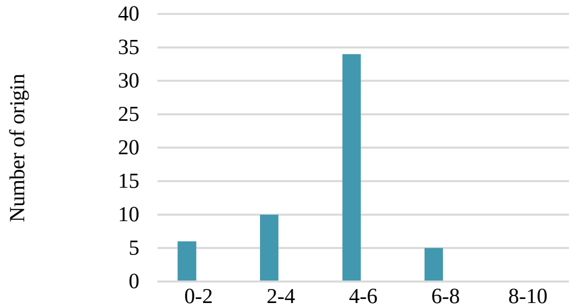


Figure 9. Travel distance of truck by mine road (dry season)



	0-2	2-4	4-6	6-8	8-10
Talang Duku	6	10	34	5	0
Tenam	0	0	0	0	0

Travel time (hours)

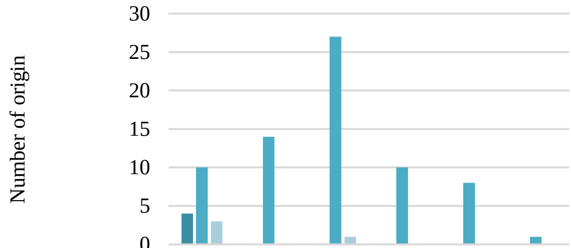
Figure 10. Travel time of truck by mine road (dry season)

Coal transport by barge

The Batanghari River can serve 74 mines sites with a maximum reach radius of 30 km. Four mine sites have good accessibility to the Pangabuan River. Meanwhile, 22 mine sites have a radius of reach to the river flow of more than 30 km. So that these coal mining areas are considered unserved by river flow during the rainy season.

The distribution graph of mileage during the rainy season shown in Figure 12 that the route travelled by barge with the destination of Tenam Port is 0-300 km. The barge trip with the destination of Talang Duku Port was 0-50 km. Meanwhile the barge trip to the terminal in Tebing Tinggi travelled 0-150 km.

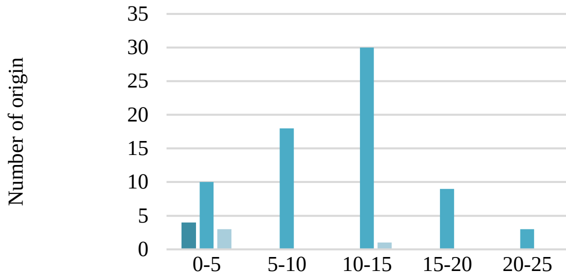
Routes to Tenam Port require 0-25 hours of travel time. A total of 48 out of 70 routes from the mine to Tenam Port require 5 hours to 15 hours of travel time see in Figure.



	0-50	50-100	100-150	150-200	200-250	250-300
Talang Duku	4	0	0	0	0	0
Tenam	10	14	27	10	8	1
Tebing Tinggi	3	0	1	0	0	0

Distance (km)

Figure 12. Travel distance of barge (rainy season)

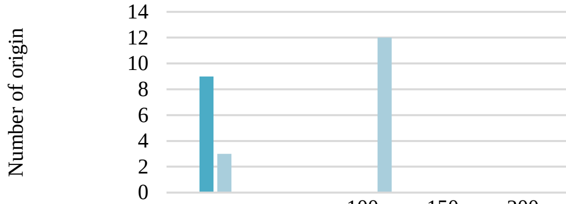


	0-5	5-10	10-15	15-20	20-25
Talang Duku	4	0	0	0	0
Tenam	10	18	30	9	3
Tebing Tinggi	3	0	1	0	0

Travel time (hours)

Figure 11. Travel time of barges (rainy season)

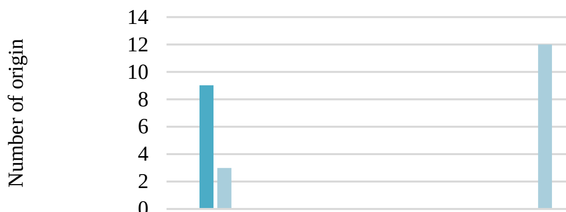
The distance travelled by barges during the dry season with the destination of Talang Duku Port is 0-50 km. To get to the terminal in Tebing Tinggi, the barge travelled 0-150 km. Meanwhile, Tenam Port cannot serve barge transport. The distribution of the distance of transport trips by barge can be seen in Figure 13. The time required for the barge to travel to Talang Duku Harbour is 0-2 hours. Meanwhile, the route to the terminal in Tebing Tinggi takes between 0-10 hours. The barge travel time is summarised in Figure 14.



	0-50	50-100	100-150	150-200	200-250
Tenam	0	0	0	0	0
Talang Duku	9	0	0	0	0
Tebing Tinggi	3	0	12	0	0

Distance (km)

Figure 13. Travel distance of barge (dry season)



	0-2	2-4	4-6	6-8	8-10
Tenam	0	0	0	0	0
Talang Duku	9	0	0	0	0
Tebing Tinggi	3	0	0	0	12

Travel time (hours)

Figure 14. Travel time of barge (dry season)

Coal transport by railway

As a result of the spatial analysis, the largest distribution of trips during the rainy season was trips to Tenam Port, 70 out of 99 routes. There were 9 trips to Talang Duku Port and 18 trips to the terminal in Tebing Tinggi (Figure 16).

The distance travelled from the mining area to Talang Duku Port by train is 0-50 km. The distance travelled to Tenam Port is between 0-200 km. While the terminal destination in Tebing Tinggi is 0-100 km from the mining area. The distribution of mileage can be seen in Figure 15.

The results of spatial analysis, during the dry season, coal transport train trips with the destination of Talang Duku Port totalled 61 routes. The trips with the destination of the terminal in Tebing Tinggi totalled 38 routes. This means that the total number of routes during the wet and dry seasons is the same, namely 99 routes.

The graph of the distribution of railway mileage during the dry season in Figure 17 shows that journeys from all mine sites to final destinations range from 0 km to 250 km. The average distance travelled to the Port of Talang duku is 101 km, while the average distance travelled to the Terminal in Tebing Tinggi is 127 km. The distribution of train travel time during the dry season shown in Figure 18 shows that the travel time ranges between 0-4 hours. The average travel time to Talang Duku Port is 1.5 hours and to Tebing Tinggi is 1.8 hours.

3.3 Generalised Cost

The generalised cost, as shown in Figure 19, is the sum of the costs of travelling by the selected modes based on each trip origin. In determining mode choice preferences, the generalised cost is separated into the generalised cost of multimodal transport.

3.4 Mode Choice Utilities

The results of multinomial regression analysis on coal transport mode choice using SPSS Statistic 27 software show that the cost or tariff of coal transport trips per unit distance has no influence on the utility of mode choice. This is because the freight transport model is inelastic to the cost or fare per distance. However, the mode choice for freight transport is more elastic to the generalised cost in accordance with the statement in the previous literature [1]

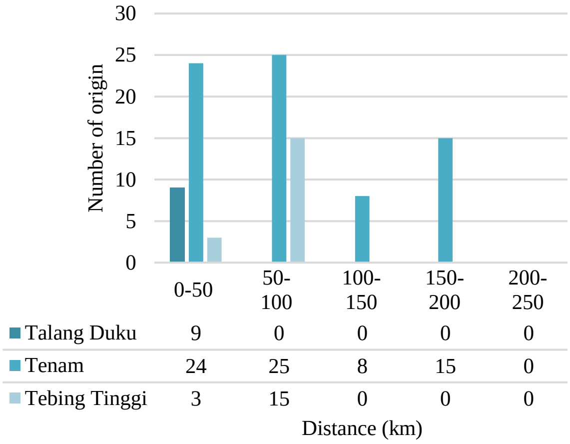


Figure 15. Travel distance of train (rainy season)

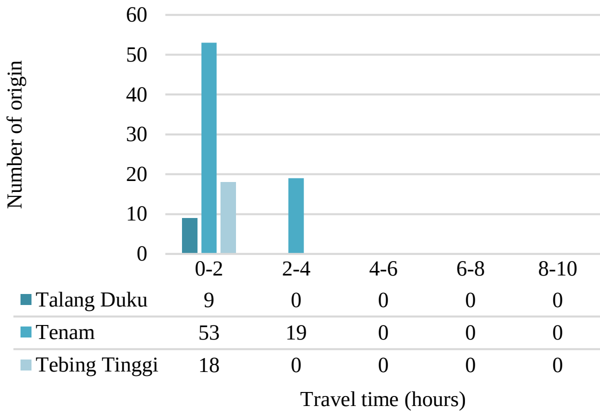


Figure 16. Travel time of train (rainy season)

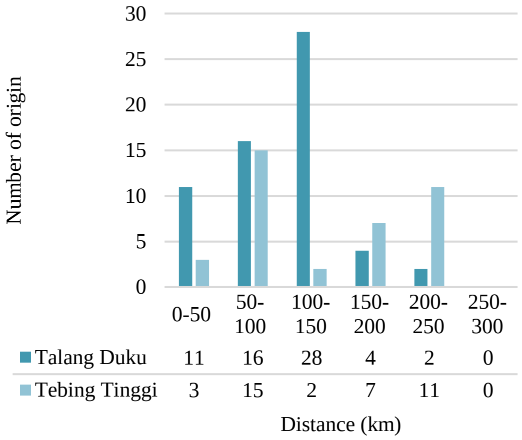


Figure 17. Travel distance of train (dry season)

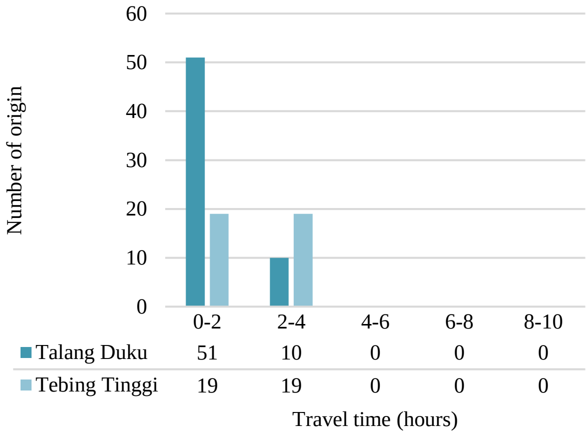


Figure 18. Travel time of train (dry season)

Parameter estimates for multimodal mode choice with the comparison of railway presented in Table 5 can be described as follows: the odds ratio value of the travel time variable on the preference for truck shows, every increase in the travel time variable for 1 hour and other variables remain constant, the possibility of choosing the truck mode as coal transport is 0.984 times lower. While the odds ratio value on the climate variable, if it is 1 or during rainy conditions, the probability of choosing the truck mode of transport increases 5.046 times if other variables are constant.

Table 5. Estimated parameters of mode choice

Preferences		B	Std. Error	Sig.	Exp(B)
Truck	Intercept	-1.590	0.269	0.000	
	Time	-0.016	0.025	0.539	0.984
	Cost	0.000	0.000	0.006	1.000
	Climate	1.619	0.176	0.000	5.046
Barge	Intercept	-1.949	0.298	0.000	
	Time	0.163	0.023	0.000	1.177
	Cost	0.000	0.000	0.001	1.000
	Climate	1.121	0.170	0.000	3.068

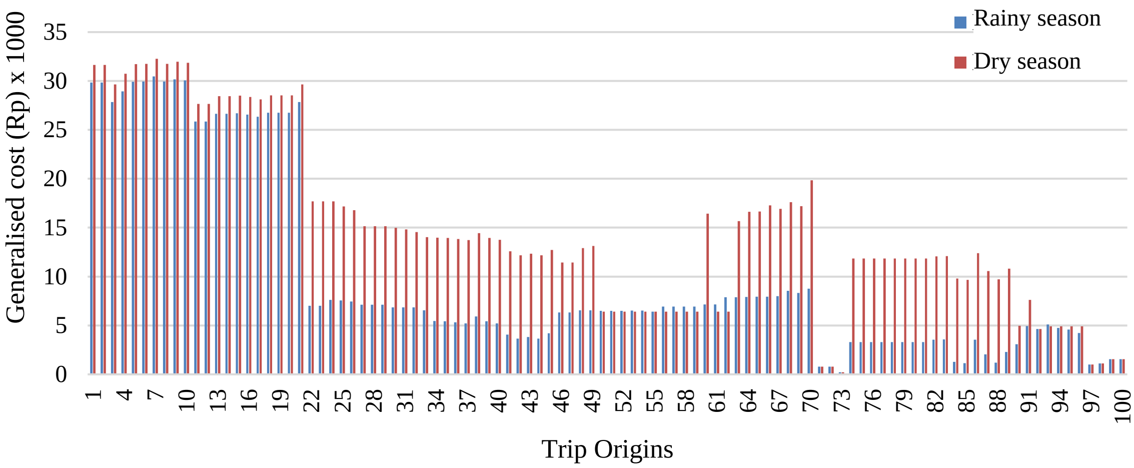


Figure 19. Generalised cost each origin

In barge preferences, an increase of 1 hour in the travel time variable is likely to increase the probability of choosing the barge mode by 1.177 times. The odds ratio value on the climate variable shows that probability of choosing barge increases 3.068 times if the rainy season and other variables are constant. Thus, the utility of truck mode (U_T) can be written as follows:

$$U_T = -1.590 - 0.016(TT_T) + 1.619(Climate)$$

Where TT_T is the travelling time of the truck. Utility barge mode can be written as follows:

$$U_B = -1.949 + 0.163(TT_B) + 1.121(Climate)$$

Where TT_B is the travelling time of the barge.

3.5 Probability of Mode Choice

Based on the utilities that have been developed, the likelihood of the optimal mode chosen for coal transport in Jambi Province can be calculated. Figure 20 shows that the likelihood of barge mode being selected as coal transport is higher than other modes during the rainy season. Figure 21 shows that during the dry season, the coal shipment by railway is chosen higher than other modes.

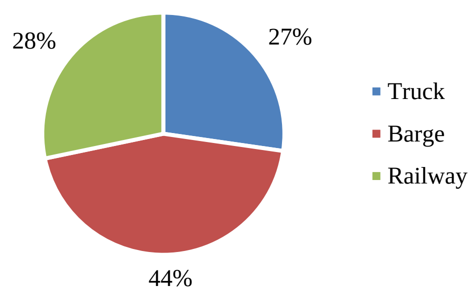


Figure 201. Coal mode choice probability (rainy season)

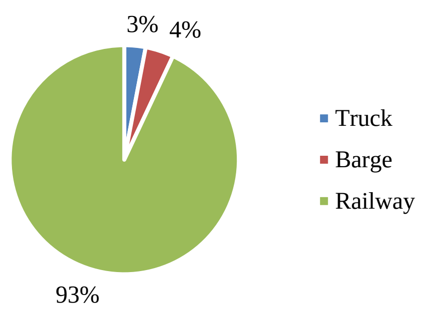


Figure 21. Coal mode choice probability (dry season)

Based on the probability of mode choice, barge transport is the mode with the highest probability to be selected. This indicates that the costs incurred by shippers for coal transport using barges are lower than other modes. However, coal shipment using barges is highly dependent on climatic conditions that affect the condition of the shipping channel. When barges cannot operate, in this case during the dry season, the cost of transporting coal using railway is lower when compared to trucks. Referring to the results of the study, both from the generalised cost and mode choice, coal shipment by barge and railway is very suitable to be selected by mining enterprises as a distribution mode.

4. Conclusion

After modelling the transportation of coal transport in the administrative area of Jambi Province, it can be summarised into several important things as follows. The portion of coal shipment by truck and railway during the rainy season is almost the same, which means that both modes have almost the same transport costs during the rainy season. Based on the proportional choice of multimodal transport during the rainy season, the probability of transport by barge via river is higher than other modes. While during the dry season, the probability of transporting by railway is higher. With the high probability of barging via river route, it can be stated that the most efficient transport is done during the rainy season. Compared to transporting coal using trucks under current conditions, coal mining companies can save on transport costs when using barges and trains.

References

[1] M. Beuthe, B. Jourquin, J. F. Geerts, and C. Koul À Ndjang'Ha, Freight transportation demand elasticities: a geographic multimodal transportation network analysis, *Transportation Research Part E: Logistics and Transportation Review*, vol. 37, no. 4, pp. 253–266, 2001.

[2] J. Binsuwadan, G. De Jong, R. Batley, and P. Wheat, The value of travel time savings in freight transport: a meta-analysis, *Transportation*, vol. 49, no. 4, pp. 1183–1209, 2022.

[3] D. A. Hensher and K. J. Button, Eds., *Handbook of Transport Modelling*. Emerald Group Publishing Limited, 2007.

[4] F. W. Jhon, M. Asyik, and Bochori, Model transportasi pengangkutan batubara ke lokasi dumping dengan metode sudut barat laut dan metode biaya terendah pada PT. Bukit Asam (Persero), Tbk, Thesis, Universitas Sriwijaya, Palembang, 2016.

[5] N. Mahmudah, D. Parikesit, S. Malkhamah, S. Priyanto, and M. Zuidgeest, Modeling freight transportation for crude palm oil (CPO) in Central Kalimantan, 2011.

[6] F. Mahmuddin, S. Klara, S. Hariyanto, H. Rivai, and A. T. Qurrohman, Prediksi capaian kecepatan kapal terhadap daya mesin utama tugboat pada variasi beban muatan tongkang, *Jurnal Teknik*, vol. 4, 2018.

[7] P. Pradono, I. Syabri, S. Y. R., and M. Fathoni, Comparative analysis on integrated coal transport models in South Sumatra, *Journal of Environmental Treatment Techniques*, 2019.

[8] D. Setiawan, Pembatasan kecepatan maksimum dan kaitannya terhadap kapasitas lintas jalur kereta api Muara Enim–Lahat Sumatera Selatan, in *Prosiding Seminar Nasional Teknik Sipil*, 2016, pp. 36–46.

[9] L. T. Suryawati, N. Nahry, F. Indriastiwi, and S. P. Hadiwardoyo, Generalized cost of freight multimodal system in Java, *International Journal of Supply Chain, Operation Management and Logistics*, vol. 3, no. 5, pp. 14–25, 2022.

[10] H. Wijaya, Purnawan, and H. Gunawan, Penentuan tarif angkutan barang moda kereta api jalur Padang–Solok, 2014.

[11] O. Willumsen, J. De Dios Ortúzar, and L. G. Willumsen, *Modelling Transport*, 4th ed. West Sussex: John Wiley & Sons, Ltd., 2011.