JOURNAL OF WORLD SCIENCE
https://jws.rivierapublishing.id/index.php/jws
Volume 3 No. 10 October 2024
P-ISSN: 2828-8726
E-ISSN: 2828-9307

POTENTIAL APPLICATION OF ELECTRONIC ROAD PRICING (ERP) ON ROADS IN BANDUNG CITY

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ABSTRACT
This research investigates the potential implementation of Electronic Road Pricing (ERP) in Bandung City, Indonesia, focusing on its effectiveness in reducing traffic congestion. The study employs a quantitative approach using a survey method, experiments, and statistical analyses to evaluate ERP's impact on road traffic performance and cost efficiency. The research design includes traffic volume analysis, vehicle operating costs, and data collection through questionnaires from Bandung residents selected randomly. The research subjects include frequent road users in congested areas, and the study was conducted in 2023. Using binary logistic regression, the results show significant shifts in road user behavior, with reductions in traffic volumes of 33% on Sukajadi Road, 38% on Dr. Djunjunan Road, and 23% on Terusan Jakarta Road. Additionally, ERP was found to improve cost efficiency in traffic management. The study concludes that ERP is a promising solution for managing congestion in Bandung, with broader implications for other congested cities in Indonesia.

Keywords: Bandung, cost efficiency, electronic road pricing, traffic congestion, traffic management.

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INTRODUCTION

Traffic congestion is a condition where, at one time, there is a build-up of vehicle volume on the road, which results in unsmooth traffic flow (Chen et al., 2024; Kan et al., 2024). Traffic congestion is caused by several factors: the increasing number of private vehicles, the unbalanced ratio of vehicles to the available roads, inadequate public transportation, and traffic accidents. Traffic congestion is a severe problem (Gañan-Cardenas et al., 2024; H. Liu et al., 2024; Zhang et al., 2024). This is because congestion can cause various negative impacts, such as wasted vehicle operational costs, additional travel time and air pollution, and hampering people's mobility. Congestion is a complex problem and requires a holistic approach involving urban planning, efficient public transportation, the use of technology to manage traffic, and public awareness of the environmental impact. Traffic congestion increases when the current is so large that vehicles are very close to each other. Total congestion occurs when vehicles have to stop or move slowly. Traffic jams occur in large countries such as China, India, the United States, and Indonesia (Agarwal, 2016; Apriyono & Rumlus, 2021; Sianipar, 2018).

Therefore, traffic management and engineering are needed. Traffic management and engineering is a series of undertakings and activities, including planning, procurement, installation, arrangement, and maintenance of road equipment facilities to create, support, and maintain security, safety, order, and smooth traffic (Ait Ouallane et al., 2022; Marzioli et al., 2024; Wang et al., 2024). Implementing traffic management and engineering improves public transportation and infrastructure (Chen et al., 2024; Z. Liu et al., 2024). In addition to improving public transportation services, several other steps are needed to reduce the use of private vehicles and encourage people to use different modes of transportation, namely the implementation of Travel Demand Management (TDM) (Pratama et al., 2022). Travel Demand Management (TDM) is a set of strategies, policies, and actions to manage regional travel demand. Where one of the goals is to reduce congestion and move towards a sustainable transportation system policy (Pratama et al., 2022). An example of a strategy or policy for implementing Travel Demand Management (TDM) is Electronic Road Pricing (ERP).

Electronic Road Pricing (ERP) is a system that charges electronically. This system will be applied to busy roads and congested areas by imposing progressive tariffs during heavy traffic. It will be charged a higher tariff than when traffic is relatively low (DKI, 2012) (Adilah & Nadjam, 2020). The implementation of Electronic Road Pricing (ERP) has two main objectives: first, to increase the income of a region or country, and second, to regulate the use of vehicles in preventing congestion (Pratama et al., 2022). The implementation of ERP has been widely applied in countries with high levels of congestion, and the implementation of Electronic Road Pricing (ERP) in Singapore is the first system designed specifically for road congestion pricing. So that Electronic Road Pricing (ERP) also has the potential to be applied to the city of Bandung, Indonesia.

Bandung is the capital of West Java Province and one of the metropolitan cities in Java, Indonesia. The city, with an area of 167.3 km^2, has a population of 2.5 million people with a population density of 14.98 / km^2 and a population growth rate of 0.92% (Rivaldi et al., 2024). Bandung has developed into a metropolitan city that plays a vital role in the dynamics of the country's growth in political, economic, and social activities in Indonesia. Bandung's rapid population and economic growth have also led to a significant increase in vehicles, including motorcycles, cars, and carfore, it is common for individuals in the modern era to face several problems related to the transportation system. In 2023, there will be 1,562,689 units of vehicles, consisting of 1,113,142 units of motor vehicles, 378,112 private cars, 5,688 buses, microbuses, and 65,742 truck pickups. Vehicle ownership that continues to increase without adequate road network infrastructure will cause an excess burden on road infrastructure capacity, which will later cause congestion. Congestion is one of the main problems. Therefore, traffic management and engineering efforts are needed to reduce the level of congestion in the city of Bandung (Arts et al., 2021; Badan Pusat Statistik, 2024, 2024; Hasibuan, 2022; Oladimeji et al., 2023; Serang & Hiariey, 2022; Yoka Pramadia, Rusydan Fathya, 2023).

Therefore, this study aims to evaluate the potential impact of ERP on road traffic performance and cost efficiency in Bandung's most congested areas. Previous studies, such as those by Pratama et al. (2022) and Agarwal (2016), have highlighted the effectiveness of ERP in reducing traffic congestion in urban centers by managing vehicle volume and encouraging the use of public transportation. These studies serve as a basis for understanding the potential benefits of ERP in Bandung, where traffic congestion has reached critical levels, particularly in areas like Sukajadi Road and Dr. Djunjunan Road. By analyzing the effectiveness of ERP in these critical locations, this research seeks to offer practical solutions for improving traffic flow and reducing operational costs.

This study aimed to determine the influence of ERP on road traffic performance and cost efficiency due to congestion on the most congested roads in Bandung. By effectively implementing electronic road pricing, it is hoped that people will switch to using public transportation and that traffic volume will be better controlled to overcome congestion at several points in Bandung (Ozaki, 2020).

METHOD

This research uses quantitative methods, including surveys, experiments, and statistical analysis. The data collection process in this study uses a questionnaire with a sample of respondents randomly selected from the population, namely the residents of the city of Bandung. The independent variables include the frequency of trips and the cost sensitivity of ERP. In contrast, the dependent variable is the movement of road users in the implementation of Electronic Road Pricing (ERP). The collected data can be calculated using the binary logistic regression method. The research hypothesis is that the frequency of trips and ERP fares have a party partial effect on deep road users. The binary logistic regression method includes the classification plots test, the hommer Lemeshow goodness of fit test, and the iteration history test (Adilah & Nadjam, 2020; Hayati, 2014). Data processing will be carried out using statistical software such as SPSS (Statistical Package for the Social Sciences) to ensure the accuracy and reliability of the calculation results. This study's data sources come from primary and secondary data.

The research was conducted in Bandung City, West Java, the capital of West Java Province and one of Indonesia's most populous cities. The research location was selected based on the 2023 Volume and LHR Final Report information. The research was carried out on the three busiest roads in Bandung, namely, Sukajadi Road, DR. Djunjunan Road, and Terusan Jakarta Road. Sukajadi is an urban road (Arteri) with a road type 2/1 TT and a road length of 2.1 km. Dr. Djunjunan Road is an urban road (Arteri) with a 6/2 T road type and a road length of 2.13 km. The Jakarta Canal Road is an urban road (Arteri) with a 4/2 T road type and a road length of 1.91 km (Bandung City Transportation Office, 2023). This study uses the 2023 Indonesian Road Capacity Guidelines as the main guideline to analyze traffic characteristics in the urban road capacity section (Mustifa et al., 2024).

1. Vehicle Volume Calculation

   Daily traffic volume data was obtained based on the results ducted by the Bandung City Transportation Office in the range of 06.00 – 20.00 WIB. Furthermore, the data must be converted into standard vehicle units per hour (SMP/hour) using Passenger Car Equivalent (EMP) values (Li, 2024).

2. Capacity Calculation (C) (Hosseinpour, 2024)

$$C = C_0 \ x \ FC_{LJ} \ x \ FC_{PA} \ x \ FC_{HS} \ x \ FC_{UK}$$

3. Degree of Saturation

$$DJ = \frac{q}{C}$$

The cost of congestion is the economic and social cost that arises from density and congestion. Congestion costs are calculated using the Rupiah value as the final result that road users must bear (Sanda et al., 2019).

$$C = N\left[GA + \left(1 - \frac{A}{B}\right)V'\right]T$$

The value of travel time is an economic measurement of the value of time spent by an individual or society in traveling (Sanda et al., 2019).

$$\lambda = \frac{\frac{PDRB}{Total\ Population}}{Annual\ Working\ Time}$$

A vehicle uses queue/delay time in traffic when stopped or moving very slowly in a queue or traffic jam.

$$T = W_T e - W_T\ i$$

Vehicle operating costs are all associated with using and maintaining a vehicle over time. Calculation of vehicle operational costs based on the guidelines of Pd T-15-2005-B Department of Public Works Sub-Committee for Transportation Infrastructure Engineering (Mishra & Mehran, 2024).

$$BOK = BT + BTT$$

a. Fixed Fee (BT)

$$BT = Depreciation\ Rate + Overhead\ Cost$$

b. Non-Fixed Fee (BTT)

$$BTT = BiBBMj + BOi + BPi + BUi + Bbi$$

Binary logistic regression is a statistical method used to show the relationship between one or more independent and binary dependent variables. Response variables have dichotomous properties, with only two value options: "Agree" and "Disagree." In contrast, a predictor variable can be continuous or fall into more than one category (Putri et al., 2021).

1. SPSS Data Processing

$$\pi(x) = \frac{exp^{(\beta 0+\beta 1x)}}{1 + exp^{(\beta 0+\beta 1x)}}$$

2. Congestion Cost Efficiency Calculation

$$P(a) = \frac{n(A)}{n(S)}$$

$$n = P(a)\ x\ \pi(x)$$

$$Efficiency = C\ x\ n$$

RESULTS AND DISCUSSION

In determining traffic characteristics, it is necessary to have an actual capacity that can be obtained by using the Capacity Calculation formula, after which it can find the degree of saturation with the Degree of Saturation formula so that you get the busiest hours in the morning, afternoon and evening, along with the LOSS of service.

1. Capacity Calculation

$$C = C_0\ x\ FC_{LJ}\ x\ FC_{PA}\ x\ FC_{HS}\ x\ FC_{UK}$$

$$C = 2800\ x\ 1{,}29\ x\ 1\ \ x\ 0{,}94\ x\ 1\ = 3395$$

Table 1. Actual Capacity

Street Name	Sukajadi Road	Dr. Djunjunan Road	Jakarta Canal Road
C	3395	3147	3465

Table 1 shows that Dr. Djunjunan Road has the smallest actual capacity, 3147, while Terusan Jakarta Road has the most significant actual capacity, 3465.

2. Degree of Saturation

$$DJ = \frac{q}{C}$$
$$= \frac{2532}{3395} = 0{,}75$$

Table 2. Degree of Saturation of Sukajadi Road

NO	TIMES	VOLUME		C	Q/C	LOSS
		KEND	Junior High School/HOUR			
1	08.00 - 09.00	4283	2532	3395	0,75	D
2	14.00 - 15.00	4226	2554	3395	0,75	D
3	16.00 - 17.00	4364	2651	3395	0,78	D

Table 3. Degree of Saturation of Dr. Djunjunan Road

NO	TIMES	VOLUME		C	Q/C	LOSS
		KEND	Junior High School/HOUR			
1	08.00 - 09.00	7251	4383	3147	1,39	F
2	12.00 - 13.00	6702	4343	3147	1,38	F
3	16.00 - 17.00	8196	4635	3147	1,47	F

Table 4. Degree of Saturation of Jakarta Canal Road

NO	TIMES	VOLUME		C	Q/C	LOSS
		KEND	Junior High School/HOUR			
1	08.00 - 09.00	7251	4383	3465	1,26	F
2	12.00 - 13.00	6702	4343	3465	1,25	F
3	16.00 - 17.00	8196	4635	3465	1,34	F

In the table of saturation degrees, Dr. Djunjunan Road and Terusan Jakarta Road get Loss F, meaning the two roads' saturation degree is > 1. Describes traffic conditions that often occur with congestion and long queues. At this rate, their vehicle speed decreases by 30km/h, and when there is a queue of vehicles, the speed can decrease to 0.

Next, to find out the cost of congestion on the three roads using the calculation of congestion costs formula, but before that, it must first find the time value with the value of time formula, the queue time with the Queue/delay time in traffic formula, the Operational Cost with the formula vehicle operational costs which consists of fixed costs (BT) and non-fixed costs (BTT).

3. Time value

$$\lambda = \frac{\frac{351.284.450}{2.506.603}}{2080} = 0{,}0674\ Rupiah\ /\ hour$$

4. Queue Time (Delay)

$$T = W_T e - W_T\, i$$
$$= 0{,}136 - 0{,}106 = 0{,}029\ /\ \text{hour}$$

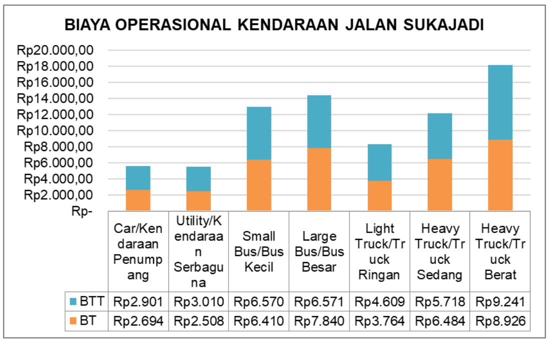
Table 5. The Time Value of the Third Road Section

STREET	TIMES	TRAVEL TIME		QUEUE (T)
		IDEAL	EXISTING	
Sukajadi	08.00 - 09.00	0,106	0,136	0,029
	12.00 - 13.00	0,106	0,144	0,037
	16.00 - 17.00	0,106	0,179	0,073
Dr. Djunjunan	08.00 - 09.00	0,055	0,069	0,014
	12.00 - 13.00	0,055	0,065	0,010
	16.00 - 17.00	0,055	0,074	0,019
Jakarta Canal	08.00 - 09.00	0,058	0,083	0,025
	12.00 - 13.00	0,058	0,081	0,023
	16.00 - 17.00	0,058	0,084	0,026

After calculating the queue time, the highest score was obtained in the n on Sukajadi Road, Dr. Djundjuan Road, and Terusan Jakarta Road.

5. Vehicle Operating Costs

$$BOK = BT + BTT$$



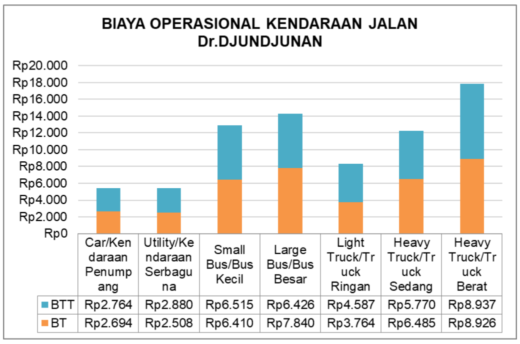


Diagram 1.
Vehicle Operating Costs (BOK) Sukajadi Road

Diagram 2.
Vehicle Operating Costs (BOK) Dr. Djunjunan Road

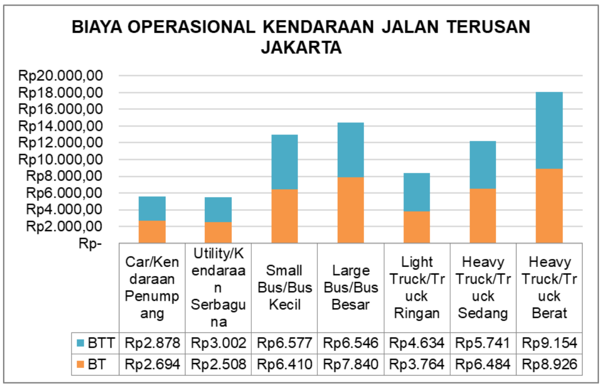


Diagram 3.
Jakarta Canal Road BOK

Table 6. Operational Costs of Vehicles on the Third Road Section

Number of BOK	BT (Rp/km)	BTT (Rp/km)	BOK (Rp/km)
Sukajadi	IDR 38,628.02	IDR 38,624.55	IDR 77,252.57
Dr. Djunjunan	IDR 38,628.02	IDR 37,878.72	IDR 76,506.74
Jakarta Canal	IDR 38,628.02	IDR 38,531.46	IDR 77,159.47

Heavy Truck/Heavy Truck has the highest operational cost value. At the same time, a utility vehicle/multipurpose vehicle is the type of vehicle with the lowest operational cost value, with a difference that is not much different from a car/passenger vehicle.

6. Congestion Fees

$$oneC = N\left[GA + \left(1 - \frac{A}{B}\right)V'\right]T$$
$$= 2532\left[77252{,}57\ x\ 23{,}5 + \left(1 - \frac{23{,}5}{30}\right)0{,}0674\right]0{,}029$$
$$= Rp135.205.334\ /\ hour$$

Table 7. Cost of Congestion on the Third Road Section

	Congestion Fees		
Road/Time	**Sukajadi Road**	**Djunjunan Road**	**Jakarta Canal Road**
Morning	IDR 135,205,334/Hour	IDR 163,383,722/Hour	IDR 193,760,827/Hour
Noon	IDR 163,656,024/Hour	IDR 120,293,284/Hour	$Rp\ 182.312.536/Jam$
Afternoon	IDR 265,675,914/Hour	IDR 210,213,417/Hour	IDR 211,152,514/Hour

Based on Table 7, the most considerable congestion cost value was obtained in the afternoon on Sukajadi Road because the existing speed on Sukajadi Road is only 17.8 km/h. The last step is to find cost efficiency due to congestion based on questionnaires that have been distributed to a predetermined sample and with the indicator of travel frequency and cost continuity of ERP implementation on the movement of road users using binary logistic regression in the SPSS application, then processed using formula SPSS Data Processing after that to find out the opportunity of moving road users using formula Congestion Cost Efficiency Calculation and obtaining the value of cost efficiency due to congestion using Cost Efficiency Calculation formula.

Table 8. Output Variable in the Equation block 1 Sukajadi Road

Sukajadi Road		B	S.E.	Wald	Df	Sig.	Exp(B)
Step 1	Frequency	-.032	.313	.010	1	.919	.969
	Fare1(1)	3.180	.779	16.663	1	.000	24.052
	Tariff 2 (1)	1.011	.799	1.598	1	.206	2.748
	Tariff 3 (1)	1.026	1.118	.842	1	.359	2.789
	Tariff 4 (1)	.237	1.160	.042	1	.838	1.267
	Constant	-3.114	1.131	7.583	1	.006	.044

The results of data processing with SPSS showed that Tariff 1 (Rp 5,000—Rp 15,000) was a variable that significantly influenced respondents' decision to pass through the road that would be applied Electronic Road Pricing (ERP) compared to Tariff 2 (Rp. 5,000—Rp 20,000), Tariff 3 (Rp. 5,000—Rp. 25,000), Tariff 4 (Rp. 5,000—Rp. 30,000), and travel frequency.

7. Cost Efficiency of Congestion

$$\pi(x) = \frac{exp^{(\beta 0+\beta 1x)}}{1+ exp^{(\beta 0+\beta 1x)}}$$
$$= \frac{exp^{(-3,114+3,180(1))}}{1+ exp^{(-3,114+3,180(1))}} \quad = 0,51$$

$$P(a) = \frac{n(A)}{n(S)}$$
$$= \frac{66}{100} \quad = 0,66$$

$$n = P(a)\ x\ \pi(x)$$
$$= 0,66\ x\ 0,51$$
$$= 0,33 = 33\%$$

Table 9. The Value of Influence and Opportunities for Road User Mobility

Street Name	Sukajadi Road	Dr. Djunjunan Road	Jakarta Canal Road
Value of the influence of road user displacement	0,51	0,54	0,35
Opportunities that keep passing	0,66	0,72	0,67
Opportunities for road user displacement	33%	38%	23%

Based on the results of the questionnaire that Dr. Djunjunan conducted for road users, 72% of them could continue to pass through the road if ERP is implemented, 67% for Terusan Jakarta Road, and 66% for Sukajadi Road.

Table 10. Cost Efficiency of Congestion

	Efficiency		
Road/Time	**Sukajadi Road**	**Dr. Djunjunan Road**	**Jakarta Canal Road**
Morning	IDR 44,617,760 / Hour	IDR 62,085,815 / Hour	IDR 44,564,991/ Hour
Noon	IDR 54,006,488 / Hour	IDR 45,711,448 / Hour	IDR 41,931,884/ Hour
Afternoon	IDR 87,673,053 / Hour	IDR 79,881,099 / Hour	IDR 48,565,079 / Hour

After the overall data processing, the highest efficiency value was obtained: Dr. Djunjunan Road at 38%, Sukajadi Road at 33%, and Terusan Jakarta Road at 23%.

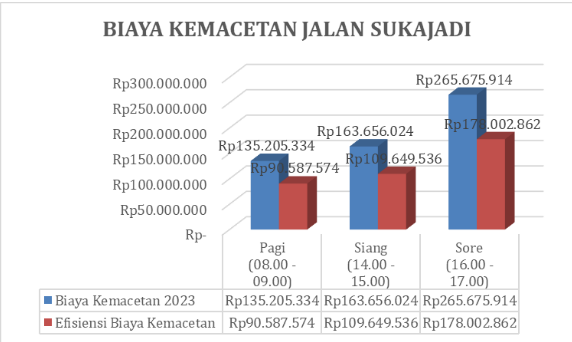


Diagram 4
Cost of Sukajadi Road Traffic Jam

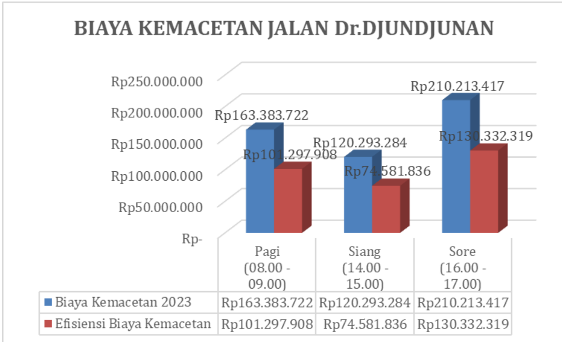


Diagram 5
Dr. Djunjunan Road Congestion Cost

Diagram 6
Jakarta Canal Road Congestion Cost

Based on the results obtained, the reduction in costs due to congestion on the three roads is relevant to the research on Road Medan Merdeka Barat, DKI Jakarta, with a decrease of 50%. In addition, ERP in Singapore can reduce passenger car traffic in the inner-city center by 20-30%, increase the use of public transport, and reduce private vehicles (Adilah & Nadjam, 2020; Agarwal, 2016; Menon & Guttikunda, 2010; Wolniak & Grebski, 2023).

This ERP system has the potential to be implemented to overcome congestion in the city of Bandung because it only takes two years to reach the BreakEvenPoint (BEP) if referring to the implementation of ERP in Singapore. Since its establishment in September 1998, ERP in Singapore has required capital of S$197 million, with 66 control gates requiring an annual cost of S$25 million for operations and maintenance (2009 data). From 2008 to 2009, the program was estimated to generate an annual revenue of S$144 million (Menon & Guttikunda, 2010).

CONCLUSION

After all data processing was carried out and a conclusion was obtained, namely for the traffic characteristics of Sukajadi Road, the degree of saturation was obtained of 0.75 in the morning and noon, was 0.78 in the afternoon, which means it is included in the level of Service Row D. As for Dr. Djunjunan Road of 1.39 in the morning, 1.38 in the afternoon and 1.47 in the afternoon which means it is included in the level of Service Lodge F. And Road Canal Jakarta is 1.26 in the morning, 1.25 during the day and 1.34 in the afternoon which means it is included in the level of Los Ministries F.

For the value of costs due to congestion, the most significant loss can be in the afternoon on each road with the amount of Sukajadi Road, which is Rp. 135,205,334/Hour in the morning, Rp 163,656,024/Hour during the day, Rp 265,675,914/Hour in the afternoon. As for Dr. Djunjunan Road, amounting to Rp. 163,383,722/Hour in the morning, Rp. 120,293,284/Hour during the day, and Rp 210,213,417/Hour in the afternoon. Also, the cost due to congestion on Jakarta Canal Road is Rp. 193,760,827/Hour in the morning, Rp. 182,312,536/Hour during the day, and Rp. 211,152,514/Hour in the afternoon.

In addition, the value of congestion cost efficiency is obtained based on the results of the opportunity to move road users with the influence of travel frequency and cost sensitivity of 33% for Sukajadi road, 38% for Dr. Djunjunan road, and 23% for Jakarta Canal Road. Therefore, the value of congestion cost efficiency still has the opportunity to increase along with the fulfillment of various supporting aspects of implementing electronic road pricing in Bandung. The application of electronic road pricing on Bandung City Roads can be considered more deeply because it not only reduces the cost of congestion but can also increase regional revenue, which helps improve transportation facilities and infrastructure in the city of Bandung.

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