ISSN 1533-9211

DOI: 10.5281/zenodo.13822937

UNLOCKING JAKARTA'S TRAFFIC SOLUTION: CLUSTERING OF 25 ODD-EVEN ROADS FOR THE BATTERY ELECTRIC VEHICLE POLICY

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Abstract

The odd-even license plate policy is a key initiative by the Jakarta Provincial Government to reduce private vehicle usage on designated roads to combat traffic congestion. Since its inception, the number of roads under this policy has steadily increased from 5 in 2016 to 25 in 2019, covering various areas of Jakarta, including West, Central, East, and South Jakarta. Despite the policy's expansion, data indicates an unexpected rise in passenger vehicle purchases in Jakarta and surrounding regions, suggesting limited effectiveness in reducing traffic congestion. Furthermore, while Battery Electric Vehicles (BEVs) were exempted from the odd-even restriction starting in 2019, the adoption rate of BEVs has not kept pace with the growth of Internal Combustion Engine (ICE) vehicles. Currently, ICE vehicles continue to dominate the roads under the odd-even policy. To identify the most effective strategies for managing ICE vehicle usage, a k-means clustering analysis is proposed to assess the characteristics of the 25 odd-even roads, including road capacity, average speed, and traffic congestion. By clustering these roads based on their unique characteristics, more targeted and efficient policies can be developed to promote sustainable urban mobility and alleviate congestion in Jakarta.

Keywords: Odd-Even License Plate Policy, Traffic Congestion, Battery Electric Vehicles (BEVs), K-means Clustering, Internal Combustion Engine (ICE) Vehicles.

INTRODUCTION

Jakarta Province is divided into five administrative city areas and one administrative district with a total area of 662.33 km². The Administrative regions of Jakarta are distributed across varying land areas: Central Jakarta spans 48.13 km², North Jakarta covers 146.66 km², West Jakarta encompasses 129.54 km², South Jakarta extends over 141.37 km², and East Jakarta comprises 188.03 km². Additionally, the Administrative District of the Seribu Islands has a total area of 8.70 km².

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.13822937

Central Jakarta has the highest population density among Jakarta's administrative cities, with 20,618 people per km². This is followed by West Jakarta at 19,679 people per km², East Jakarta at 16,879 people per km², South Jakarta at 14,452 people per km², and North Jakarta at 12,811 people per km². The total population of Jakarta stands at 10,679,951, with an annual growth rate of 0.66%. In 2022, the overall population density of Jakarta reached 16,084 people per km².

Population growth significantly impacts transportation demand, as evidenced by the increasing number of vehicles yearly. This rise in vehicle numbers necessitates adequate transportation infrastructure. However, according to data from the Central Bureau of Statistics Indonesia (2024), the total length of roads in Jakarta Province remained stagnant at 6,432 km from 2019 to 2022. This lack of expansion has contributed to traffic congestion at various points across Jakarta, particularly during peak hours, as illustrated in Figure 1.

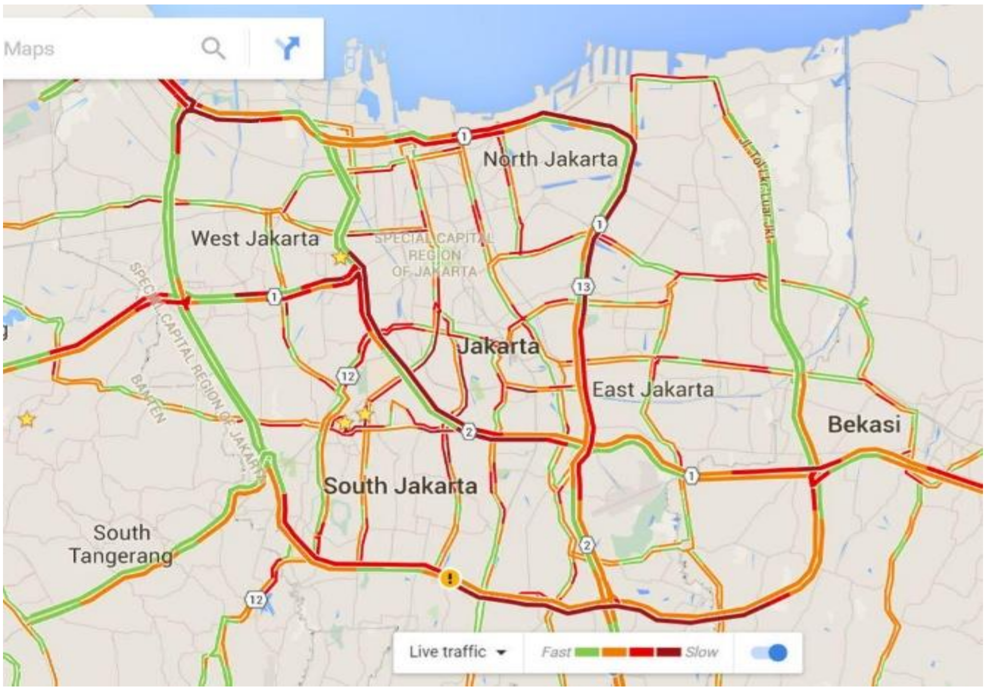

Figure 1: Traffic Congestion in Jakarta

In 2023, Jakarta ranked 30th among 387 cities worldwide for traffic congestion, with an average travel time of 23 minutes and 20 seconds per 10 km—an increase of 40 seconds from 2022—and an average speed of just 21 km/h (TomTom, 2023). Traffic congestion in Jakarta has remained a persistent issue due to the demand for transportation, particularly private vehicles, outpacing the available infrastructure (Tamin, 2000). Although public transportation options exist, they have not yet significantly curtailed the growth of private vehicle usage in the city. Cars are one of the transportation options for residents of Jakarta and its surroundings because of their comfort and practicality. However, the growth of car use on Jakarta's streets is increasing and out of control every year.

ISSN 1533-9211
DOI: 10.5281/zenodo.13822937

The government plays a crucial role in shaping the national transportation system and industry, particularly in promoting a balance between transportation demand and available infrastructure. In 2016, the Jakarta Provincial Government officially replaced the "3 in 1" policy with the odd-even policy for specific roads, as stipulated in Provincial Regulation Number 164 of 2016 on traffic restrictions using the odd-even system. The "3 in 1" policy required that passenger cars have a minimum of three occupants when traveling on designated roads. In contrast, the odd-even policy mandates that passenger cars with odd-numbered license plates can only operate on certain roads on odd-numbered dates, while those with even-numbered plates are allowed on even-numbered dates.

In the following years, odd-even roads increased from 5 in 2016 to 9 roads in 2018 (Governor Regulation, 2016). Through Provincial Regulation Number 88 of 2019 concerning Traffic Restrictions with the odd-even system, the number of odd-even roads was increased to 25 roads, as shown in Figure 3 and Figure 4, effective from 9 September 2019, with the addition of electric vehicles as exempted vehicles (Governor Regulation, 2019). The exemption of Battery Electric Vehicles (BEVs) from the regulation is expected to incentivize the public to reduce the use of Internal Combustion Engine (ICE) vehicles, encouraging a shift toward BEVs or increased use of mass transportation.

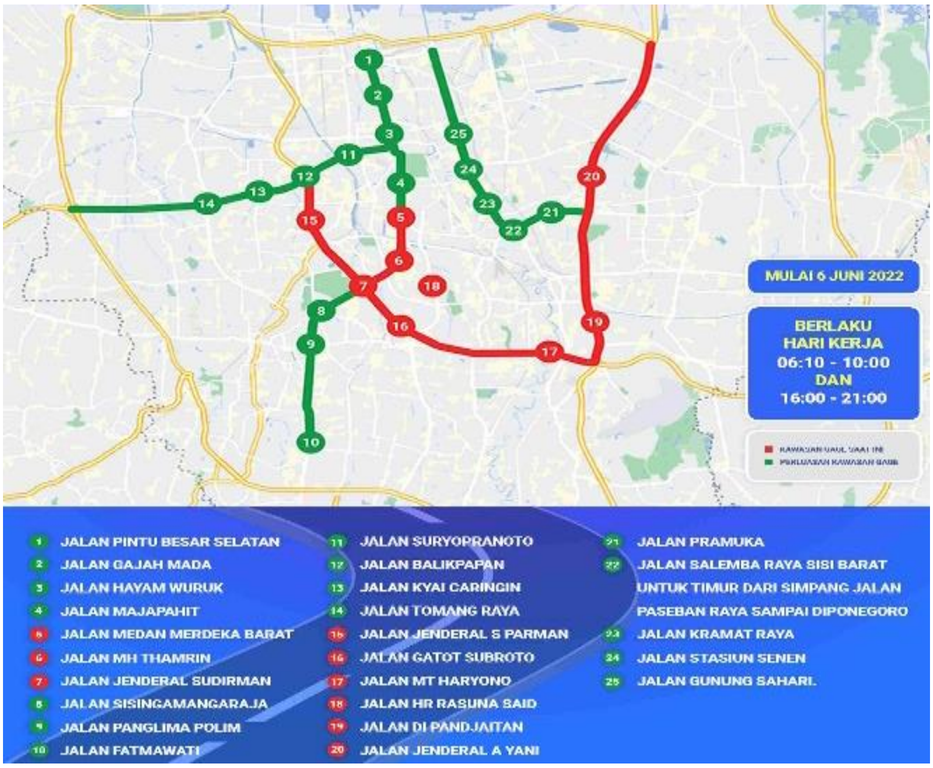

Figure 2: Odd-Even Road Section

However, data indicate that the expansion of odd-even road regulations has coincided with increased purchases of ICE passenger cars in Jakarta and its surrounding areas (Central Bureau

ISSN 1533-9211
DOI: 10.5281/zenodo.13822937

of Statistics Indonesia, 2024). Additionally, on-the-ground observations reveal that the odd-even policy has not effectively reduced traffic congestion as intended. ICE vehicles continue to dominate these roads, as they are still permitted as long as their license plates match the designated odd or even dates. This outcome conflicts with the exemption of BEVs from the policy, which aims to reduce pollution and alleviate traffic congestion (Pirmana et al., 2023). Globally, numerous policies have been implemented to promote the adoption of BEVs.

In addition, several factors hinder the adoption of electric vehicles, such as those in Poland, for example related to the price of electric vehicles, which are more expensive than ICE vehicles (Adamczyk et al., 2023). Consumer behavior, vehicle market structure, and fuel prices are challenges to the distribution of BEVs in Luxembourg and Berlin (Arababadi et al., 2021; Göhlich et al., 2021). Even in China, increasing BEV adoption can be done through mandatory fuel quality improvement (Xie et al., 2023). Around the world, many policies have been developed to support BEV adoption. Pakistan also aims to increase the number of EV cars by 30% by sharing strategies by 2030 (Asim et al., 2022). The Indian government also provides various incentives for EVs because it has been proven that the total cost of ownership in India is also more economical than ICE (Bhosale et al., 2022). Incentives for BEVs also continue to be encouraged in various countries, including California and Norway (Chakraborty et al., 2024). Reduction in parking fees and congestion costs strongly influence EV adoption at the regional level (Grythe et al., 2022).

Non-fiscal policy incentives can also be helpful in supporting the implementation of EVs (Clímaco & Henggeler, 2023). Determining routes that can only be accessed by electric vehicles is one of the efforts to increase EV implementation; besides that it can also be done by limiting ICE vehicles in certain zones in urban areas and prioritizing EV lanes such as busway lanes, parking discounts (Hoang et al., 2022).

In Indonesia, despite the development of various fiscal and non-fiscal incentives for BEVs, the transition from ICE vehicles, which remain widespread, is expected to take considerable time. Meanwhile, the purchase of ICE vehicles continues to rise significantly, contributing to increased congestion. Data on passenger car ownership in Jakarta Province from 2017 to 2022 show a substantial increase, with an average annual growth rate of 5.9%. ICE vehicles continue to dominate this growth (Haustein & Jensen, 2018). Given the rising number of ICE vehicles, a new regulation is needed to curb this growth and alleviate congestion effectively.

Effective public policy also necessitates robust public communication (Fadhli & Widodo, 2019; Wang et al., 2017). Environmental considerations are increasingly relevant in shaping environmentally friendly policies (Zolfagharian et al., 202; Iancu et al., 2023). The current odd-even policy remains widely accepted by residents of Jakarta and its surroundings. Enhancing this policy by incorporating environmental objectives is anticipated to be well-received by those seeking healthier living conditions through reduced reliance on ICE vehicles. The exemption for BEVs from the odd-even policy has been in place since 2019, making it feasible to transition from the odd-even policy to a mandatory BEV policy. This shift is contingent upon demonstrating that it effectively addresses traffic congestion. Additionally, such a transition aligns with practices adopted in other countries as part of non-fiscal policy measures.

ISSN 1533-9211

DOI: 10.5281/zenodo.13822937

This study aims to address traffic congestion on 25 odd-even road sections and explore how policies can be effectively applied based on similar road characteristics. The objectives of this study are to:

1. Cluster the 25 odd-even road sections according to their characteristics to prioritize which clusters are most suitable for implementing mandatory BEV policies to alleviate traffic congestion.
2. Identify the key variables that significantly influence the clustering of these road sections.
3. Evaluate the effectiveness of the proposed policy in reducing traffic congestion.

METHODOLOGY

Data Collection and Data Processing

The data utilized in this study are secondary sources, including the Final Report of the Traffic Characteristics Survey in Jakarta for 2023 (Direktorat Jenderal Bina Marga, 2023; Lasota et al., 2024), supplemented by supporting data from the Google Maps application. The following is a list of variables used (Table 1).

X_1 = Road Section Name

X_2 = Average speed (Km/Hour)

X_3 = Road capacity (Unit Car/hour)

X_4 = Vehicle volume (Unit/18 hour)

X_5 = Road length (Km)

X_6 = Amount of related road sections

X_7 = Amount of related odd-even sections

X_8 = level of service

Table 1: Road Section Characteristics Data

No	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
1	Balikpapan	34.0	8.111	43.435	2	9	2	C
2	D.I. Panjaitan	38.0	14.166	122.633	3	9	1	C
3	Fatmawati	32.5	7.156	63.428	5	42	1	D
4	Gajah Mada	32.5	5.810	43.382	2	28	4	D
5	Gatot Subroto	24.0	9.916	128.073	5	28	3	E
6	Gunung Sahari	32.5	11.333	79.964	3	23	1	D
7	H.R. Rasuna Said	28.0	11.333	126.769	5	25	1	D
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
25	Tomang Raya	32.0	7.265	73.611	2	8	2	D

ISSN 1533-9211
DOI: 10.5281/zenodo.13822937

The administrative area of Jakarta comprises five municipalities: Central Jakarta, North Jakarta, West Jakarta, South Jakarta, and East Jakarta, along with the Administrative District of Seribu Islands. Each area exhibits distinct characteristics in terms of population density, road infrastructure, and traffic patterns, which are essential for understanding the spatial distribution of congestion and the applicability of transportation policies. Figure 3 visually represents these administrative divisions, highlighting their respective boundaries and emphasizing their relevance in traffic management and policy implementation.

Figure 3: Administrative Area of Jakarta

In the next step, the variable X_1, representing specific characteristics of road segments, is categorized according to their respective administrative areas, as detailed in Table 2. This categorization allows for a clearer understanding of traffic-related factors distribution across different Jakarta regions. Additionally, Table 3 presents the level of service data, denoted as X_8, which reflects the operational conditions of each road segment based on traffic flow, speed, and congestion levels. These classifications provide critical insights into how each area is affected by current traffic dynamics and highlight potential zones for implementing targeted traffic management policies.

Table 2: Regional Classification Data

No	X_1	Classification Code
1	West Jakarta	1
2	Center Jakarta	2
3	South Jakarta	3
4	East Jakarta	4

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Table 3: Level of Service Classification Data

No	X_8	Classification Code
1	C	1
2	D	2
3	E	3

Clustering 25 Odd-Even Road Section

To cluster 25 roads, K-Means analysis was used. The purpose of using K-means analysis is to find out how many clusters can be created from 25 road sections. K-means clustering can be a valuable tool for analyzing Jakarta's effectiveness and optimization of the odd-even road policy. By applying K-means to traffic data, different road segments can be grouped based on similar characteristics, such as traffic volume, average speed, level of service, and congestion patterns. This approach allows policymakers to identify which clusters of roads experience the highest levels of congestion and most need targeted interventions (Jain, 2010). For instance, K-means can categorize 25 odd-even road sections in Jakarta into clusters based on key traffic variables. This clustering can help prioritize which road segments might benefit most from stricter regulations, such as transitioning to a mandatory BEV policy, thereby reducing traffic congestion and encouraging the adoption of more sustainable transportation modes (Arthur & Vassilvitskii, 2007).

Using K-means in this context also allows for identifying the main variables influencing each cluster, such as road capacity, vehicle volume, or average speed. This insight is crucial for designing policies tailored to each cluster's specific conditions, ensuring that interventions are both efficient and effective (Lloyd, 1982). Utilizing K-means clustering enables Jakarta's policymakers to refine the odd-even traffic policy by identifying the most congested road sections and tailoring interventions to specific traffic conditions. This approach facilitates the integration of broader environmental objectives and traffic management strategies, thereby advancing the city's commitment to sustainable urban mobility. The process of clusterization is explained below.

Multicollinearity Test

A multicollinearity test is conducted to see the correlation between variables, both between independent variables and between independent and dependent variables. With the following formula:

$$\text{Tolerance} = 1 - R^2 \quad (1)$$

$R^2 =$ Regression Coefficient Between Variables

$$VIF = \frac{1}{Tolerance} \quad (2)$$

The indicator of multicollinearity can be seen from the VIF (Variance Inflation Factor) value. If VIF ≥ 10 means multicollinearity occurs; conversely, if VIF ≤ 10, there is no multicollinearity value. Eliminating variables that experience high correlation is one effort to eliminate multicollinearity (Senaviratna & Cooray, 2019). The VIF is a critical diagnostic tool for

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DOI: 10.5281/zenodo.13822937

detecting multicollinearity among the independent variables in a regression model. Multicollinearity occurs when two or more variables are highly correlated, which can distort the results of the regression analysis by inflating the variance of the coefficient estimates.

Data Normalization

Data normalization is carried out to arrange the same scale between variables with the following matrix:

$$A_{mxn} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \quad (3)$$

Where m is the number of odd-even segments (25 sections), and n is the number of feature variables (eight). Data normalization needs to be done using the z-score method with the following formula:

$$a^*{}_{ij} = \frac{a_{ij} - \pi_j}{\sigma_j} \quad (4)$$

$a^*{}_{ij}$ = Normalized parameter a_{ij}

π_j = Average value of each variable

σ_j = Standard deviation value of each variable

Determine K-Optimum

The K-means method is used to group several variables into several groups or clusters with almost similar characteristics. The optimal number of clusters will be determined by the size of the silhouette index (Asmiatun dan Wakidah, 2018; Hidayati et al., 2021; Rosadi et al., 2023).

$$S(i) = \frac{a\ (i) b(i)}{\max ai, bi} \quad (5)$$

S (i)=silhouette index

a (i)=difference in mean values within clusters

b (i) = difference in average value between clusters

Determination of K - Optimum using silhouette values obtained using the orange data mining application. The maximum silhouette value is 1; the higher the silhouette value, the more precise the determination of the number of clusters will be (Wang et al., 2023).

Determine the primary variable that influences cluster

Principal Component Analysis (PCA) is used to determine the primary variable that affected the characteristics of 25 odd-even road sections. PCA analysis is performed to reduce overlapping information while reducing repetitive calculations (Khaleel et al., 2023; Liu et al., 2023). The following matrix can describe the normalization results of the previous matrix:

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$$A^*_{mxn} = \begin{bmatrix} a^*_{11} & \cdots & a^*_{1n} \\ \vdots & \ddots & \vdots \\ a^*_{m1} & \cdots & a^*_{mn} \end{bmatrix} \quad (6)$$

Then, calculate the covariance matrix C_{nxn}

$$C_{nxn} = \begin{bmatrix} C_{11} & \cdots & C_{1n} \\ \vdots & \ddots & \vdots \\ C_{m1} & \cdots & C_{mn} \end{bmatrix} \quad (7)$$

where is:

$$C_{ij} = cov\,(i,j) = \frac{\sum_{k=1}^{m}(a^*_{k1-}\mu_i)(a^*_{kj-}\mu_j)}{m-1} \quad (8)$$

The eigenvalue of γ_i (i= 1,2,3,...,25) of the C_{nxn} matrix is calculated, and the variance contribution rate of f_i of the ith principal component and the cumulative contribution rate of F_i of the k principal components can be obtained from the following equations:

$$f_i = \frac{\gamma_i}{\sum_{i=1}^{8}\gamma_i} \quad (9)$$

$$F_i = \frac{\sum_{k=1}^{i}\gamma_k}{\sum_{i=1}^{8}\gamma_i} \quad (10)$$

The eigenvalue shows the variance of the principal components; the greater the eigenvalue, the greater the influence of the principal component on the other components.

Determine the effectiveness of the policy

The new regulation is anticipated to address traffic congestion effectively. Simulations are required to evaluate its impact over time. The three scenarios and their corresponding simulations are explained in the following sections.

Descriptive Statistics of BEV Ownership Ratio in Jakarta

BEV adoption can be assessed through the ratio between BEV and ICE (Abas & Tan, 2024). Specifically, this ratio compares the number of BEVs in Jakarta to the overall increase in car ownership within the city.

$$BEV\ ratio = \frac{Number\ of\ BEV}{Total\ of Car\ Ownership} \quad (11)$$

Simulation of ICE Replacement Scenarios (100% of New Cars as BEVs) in Jakarta, Assuming Annual Growth Rates for ICE and BEV Vehicles Remain Consistent

a. Replacement Scenario Based on a Linear Annual Growth Rate

Vehicle replacement time indicates how long it will take to replace vehicles from ICE to BEV (Xing et al., 2019). In the last 5 (2019-2023) years, total ICE passenger car ownership was 4,019,663 units. The average increase in ICE passenger car ownership in Jakarta is 187 thousand units/year.

ISSN 1533-9211

DOI: 10.5281/zenodo.13822937

$$BEV_n = BEV_0 + (n \, x \, GBEV) \tag{12}$$

$$BEV_n = ICE_0 \tag{13}$$

$$n = \frac{ICE_0 - BEV_0}{GBEV} \tag{14}$$

BEV_n = Amount of BEV in n year (Unit)

ICE_0 = Initial number of ICE (Unit)

BEV_0 = Initial number of BEV (Unit)

GBEV = Growth rate of BEV/year (Unit)

n = Number of years

b. Scenario With Exponential Growth

The rise in EV adoption is closely tied to global efforts to reduce emissions (Calderon-Tellez et al., 2023). However, in 2023, Indonesia's market share for BEVs remains significantly lower than that of other ASEAN countries, such as Thailand at 10% and Vietnam at 3%. Indonesia's adoption of BEVs currently stands at only 1.7% (Energy Agency International, 2024). Assuming an average growth rate of 187,000 units per year (entirely BEVs) over the past five years and considering three growth scenarios of 20%, 10%, and 5%, replacing the existing ICE vehicles will take considerable time.

$$Total\ BEV = BEV_0 \, x \, \frac{(1+GBEV)^{n+1}-1}{GBEV} \tag{15}$$

$$n = \frac{\ln(\frac{ICE_0 \, x \, GBEV}{BEV_0}+1)}{\ln(1+GBEV)} - 1 \tag{16}$$

ICE_0 = Initial number of ICE (Unit)

BEV_0 = Initial number of BEV (Unit)

GBEV = Growth rate of BEV (%)

n = Number of years (Year)

Simulation for ICE Replacement on Odd-Even Road Cluster in Jakarta

The number of years required to replace all ICE with BEVs is obtained through the following equation.

a. Replacement Scenario by Linear Annual Growth Rate

$$n\ Cluster_i = \frac{ICE_0\ Cluster_i - BEV_0\ Cluster_i}{GBEV\ Cluster_i} \tag{17}$$

BEV_0 Cluster $_i$ = Initial number of BEV (Unit)
ICE_0 Cluster $_i$ = Initial number of ICE (Unit)
GBEV = Growth rate of BEV/year (Unit)
n = Number of years (Year)

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b. Replacement Scenario by Exponential Growth Rate

$$BEV\ Cluster_i = BEV_0\, x\, \frac{(1+GBEV)^{n+1}-1}{GBEV} \quad (18)$$

$$n\ Cluster_i = \frac{\ln(\frac{ICE_0\ x\ GBEV}{BEV_0}+1)}{\ln(1+GBEV)} - 1 \quad (19)$$

BEV_0 = Initial number of BEV in Cluster (Unit)

ICE_0 = Initial number of ICE in Cluster (Unit)

GBEV = Growth rate of BEV (%)

n = Number of years in every cluster (Year)

i = cluster 1, cluster 2, cluster 3

c. Road Service Quality Level

The total capacity of roads in Jakarta is 894,573 cars/hour. The total odd-even road capacity is 264,859, around 30% of the total capacity. With total BEV ownership in Jakarta of 6,306 units, there will be at least 1,892 vehicles on odd-even roads. The level of road services can be described in 5 levels, such as:

a) Level A, with the average speed above 48 km/hour,

b) Level B (40 km/hour - 48 km/hour),

c) Level C (33,6 km/hour - 40 km/hour),

d) Level D (25,6 km/hour - 33,6 km/hour)

e) Level E (22,4 km/hour - 25,6 km/hour)

Targeted average speed in every level of speed can be described with the following equation:

$$Vactual = Vfree\ x\ (1 - \frac{BEV}{Road\ Capacity}) \quad (20)$$

$$Vactual = Vtarget \quad (21)$$

$$BEV_{\max\ cluster\ i} = \left(1 - \frac{Vtarget}{Vfree}\right) xRoad\ Capacity \quad (22)$$

$V_{targeted}$ = targeted average speed (km/hour)

V_{free} = 60 km/hour

BEV = amount of BEV (Unit)

BEV_{max} = Maximum amount of BEV in targeted average speed (Unit)

i =cluster 1, cluster 2, cluster 3

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RESULTS

Road Section Characteristics Analysis

Table 4 provides a detailed overview of the characteristics of the 25 odd-even road sections in Jakarta, with specific focus on critical variables such as average speed (X_2), road capacity (X_3), vehicle volume (X_4), road length (X_5), amount of related road section (X_6), amount of related odd-even section (X_7), and level of service (X_8). The statistical analysis includes the maximum, minimum, and standard deviation values for each variable, which are instrumental in understanding the range and variability of these road characteristics.

Table 4: Road Section Characteristics Data

Analysis	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Max	38.0	17,258	156,986	6.0	42.0	4.0	3.0
Min	22.5	5,393	6,995	1.0	2.0	1.0	1.0
Standard Deviation	4.7	2,844	41,235	1.4	9.9	0.9	0.7

In detail, the average speed (X_2) on the analyzed road sections ranges from a low of **22.5 km/h** to a high of **38 km/h**, suggesting that most of the roads operate below optimal speed, implying congestion issues. Road capacity (X_3) varies significantly, with a maximum of **17,258 units/hour** and a minimum of **5,393 units/hour**, showing that road capacities differ significantly, which impacts traffic flow and congestion levels. The data on vehicle volume (X_4) shows a broad range, from **6,995 units over 18 hours** to **156,986 units over 18 hours**, which suggests that some road sections face severe congestion while others are more lightly trafficked. The road length (X_5) spans from **1 km** to **6 km**, shorter road sections may experience localized congestion, especially in densely populated areas, while longer sections could spread out traffic more evenly. The number of related road sections (X_6) varies between **2** and **42**, indicating significant variation in the complexity and connectivity of these road sections. The number of related odd-even sections (X_7) ranges from **1** to **4**, suggesting that road sections are often influenced by other nearby odd-even sections. The **level of service** (X_8) varies between **1** and **3**, reflecting the overall quality of traffic flow, which ranges from highly congested to moderately smooth, indicating room for improvement in many sections.

Multicollinearity Analysis

The results show no multicollinearity among the variables based on analyzing the eight variables (X_1 through X_8) related to the characteristics of Jakarta's odd-even road sections. This conclusion is supported by the VIF values obtained for each variable, which are significantly below the threshold of 10, a commonly accepted indicator of multicollinearity (Table 5). All VIF values are close to 1, which indicates a very low correlation between the independent variables. This suggests that each variable provides unique and independent information to the model, and the estimates of their effects are stable and reliable.

The absence of multicollinearity, as indicated by the low VIF values, ensures that the regression model developed using these variables will be robust and reliable. Thus, the model can effectively capture each variable's distinct contributions to the overall analysis of Jakarta's odd-

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DOI: 10.5281/zenodo.13822937

even road policy, enabling policymakers to make informed decisions based on sound statistical evidence.

Table 5: VIF Value

No	Korelasi	VIF
1	X1	1,09007
2	X2	1,04918
3	X3	1,41886
4	X4	1,79293
5	X5	1,57175
6	X6	1,00084
7	X7	1,02174
8	X8	1,06348

Normalization Analysis

We applied normalization to the entire dataset using Formula 4, which standardizes the data values to a standard scale. The resulting normalized values are shown in Table 6. This normalization process is crucial for ensuring that all variables are on a comparable scale, facilitating unbiased analysis during clustering. This normalized table presents data on the key characteristics of road sections in Jakarta's odd-even policy, using a scale of **0 to 1**. Each value reflects the relative standing of a specific road section for various factors like average speed, road capacity, vehicle volume, and other variables discussed in the previous section.

Table 6: Data Normalization

No	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
1	0.33	0.74	0.22	0.24	0.20	0.17	0.33	0.00
2	1.00	1.00	0.73	0.77	0.40	0.17	0.00	0.00
3	0.66	0.64	0.14	0.37	0.80	1.00	0.00	0.50
4	0.33	0.64	0.03	0.24	0.20	0.65	1.00	0.50
5	0.66	0.09	0.38	0.80	0.80	0.65	0.66	1.00
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
25	0.00	0.61	0.15	0.44	0.20	0.15	0.33	0.50

For instance, the result shows that **road section 2** ranks high in terms of speed (X_2) and capacity (X_3) but has low levels of related odd-even sections (X_7), indicating potential efficiency. **Road section 5** demonstrates high vehicle volumes (X_4), suggesting it faces heavy traffic pressure despite its good service level (X_8). A targeted intervention like BEV lanes could reduce congestion here.

Clustering 25 Odd-Even Road Sections Based on Each Characteristic

The K-means clustering was applied to group the 25 odd-even road sections in Jakarta into three distinct clusters based on their road characteristics. These clusters are instrumental in optimizing traffic management policies, particularly for implementing the mandatory BEV

ISSN 1533-9211
DOI: 10.5281/zenodo.13822937

policy. The algorithm identified three clusters, visually represented by the colors Blue, Red, and Green. **Cluster 1 (Blue Cluster)** includes the most congested roads and is the highest priority for policy intervention. These roads exhibit severe traffic bottlenecks, making them the most suitable for immediately introducing BEV-only lanes. **Cluster 2 (Red Cluster)** and **Cluster 3 (Green Cluster),** which represent moderately and lightly congested roads, can be addressed in later phases of the strategy. This phased approach ensures that traffic management and BEV adoption effectively align with road characteristics to reduce congestion and promote sustainable urban mobility.

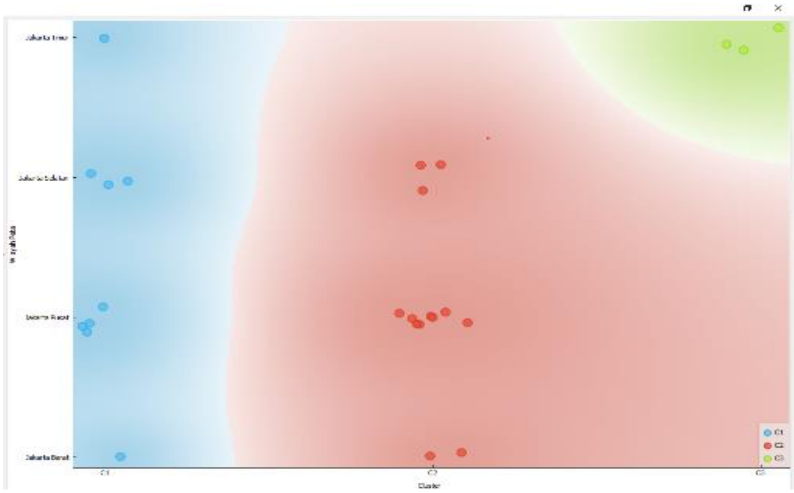

Figure 4: Cluster Region of Jakarta

The distribution map for these three clusters (Cluster 1, Cluster 2, and Cluster 3) and the grouping of odd-even road sections were determined based on region and level of service, as detailed in Table 7.

Table 7: Road Section Characteristics

Variables		Cluster 1	Cluster 2	Cluster 3
Region	West Jakarta	1	2	0
	Central Jakarta	4	8	0
	South Jakarta	3	3	0
	East Jakarta	1	0	3
Level of Services	Sufficient (C)	0	6	3
	Poor (D)	5	7	0
	Very Poor (E)	4	0	0
Average Speed	Mean	27.7	32.6	37.3
Road Capacity	Mean	9.879	9.016	13.279
Total Volume	Mean	113.081	47.544	121.279
Road Length	Mean	3.8	1.8	4.3
Amount of Road Section	Mean	22.3	12.2	20.7
Amount of Odd-Even Road Section	Mean	1.6	2.4	1.3

The following is the prioritization sequence for clusters targeted for transitioning to mandatory BEV policies:

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a. Cluster 1 (High Congestion): This cluster includes odd-even roads with high congestion levels. It consists of one road in West Jakarta, four roads in Central Jakarta, three roads in South Jakarta, and one road in East Jakarta. The average speed within this cluster is 27.7 km/h, with a level of service ranging from poor to very poor. The average road capacity is 9,879 car units per hour, while the average total vehicle volume reaches 113,081 units. The roads in this cluster have an average length of 3.8 km, with an average of 22 total roads and two designated odd-even roads (Figure 5).

Figure 5: Cluster 1 Distribution Map

b. Cluster 2 (Moderate Congestion): This cluster includes odd-even roads with moderate congestion levels. It comprises two roads in West Jakarta, eight roads in Central Jakarta, and three roads in South Jakarta. The average speed in this cluster is 32.6 km/h, with a level of service ranging from sufficient to poor. The average road capacity is 9,016 car units per hour, with an average total vehicle volume of 47,544 units. The average road length is 1.8 km, with an average of 12 total roads, including two designated odd-even roads (Figure 6).

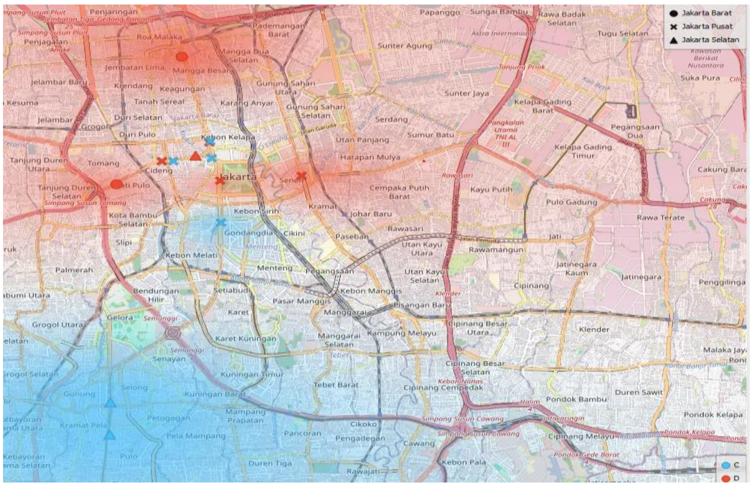

Figure 6: Cluster 2 Distribution Map

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DOI: 10.5281/zenodo.13822937

c. Cluster 3 (Light Congestion): This cluster consists of odd-even roads with light congestion levels, all located in East Jakarta (3 roads). The average speed within this cluster is 37.3 km/h, with a sufficient level of service. The average road capacity is 13,279 car units per hour, and the average total vehicle volume reaches 121,279 units. The roads in this cluster have an average length of 4.3 km, with an average of 21 total roads, including one designated odd-even road (Figure 7).

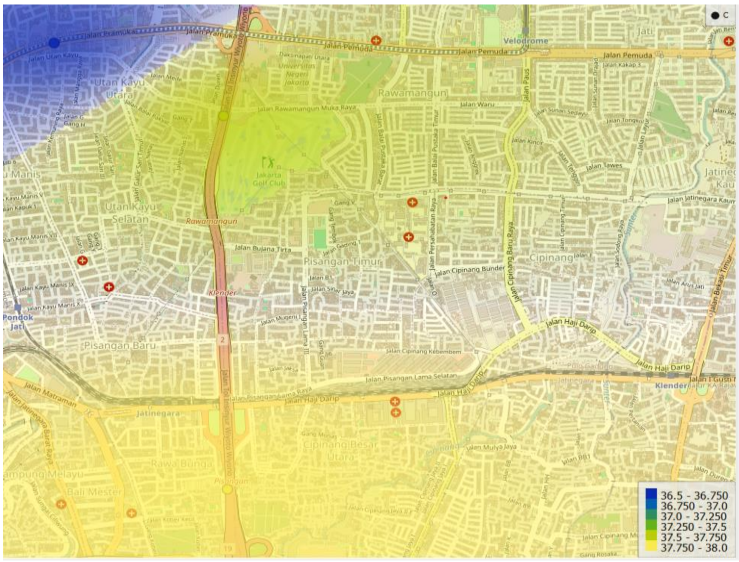

Figure 7: Cluster 3 Distribution Map

Key Variables with Significant Influence on Clustering

Based on PCA, three main components can explain up to 80% of the variance (Figure 8): regional variables, level of service variables, and a related number of section variables. The rest are explained by vehicle volume variables, road length variables, average speed variables, related odd-even section number variables, and road capacity variables.

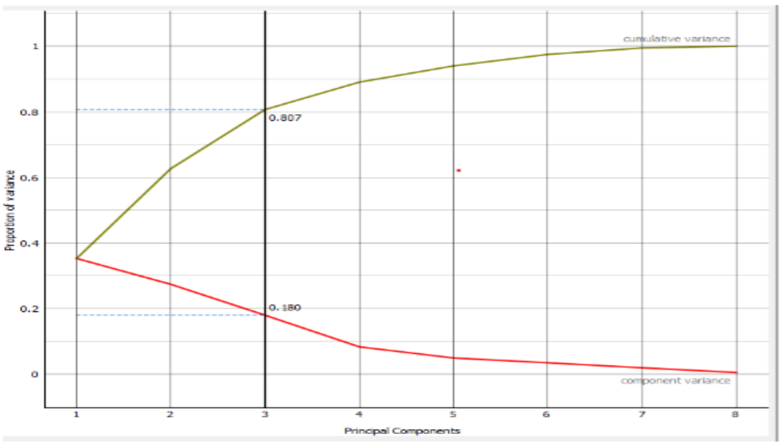

Figure 8: PCA Graphics 80 %

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DOI: 10.5281/zenodo.13822937

BEV Adoption Ratio

The analysis for the adoption of BEVs shows a very low penetration of BEVs, representing just 0.15% of the total vehicle fleet in Jakarta. Despite the Jakarta government's efforts to incentivize BEV adoption by exempting these vehicles from the odd-even road policy, the dominance of ICE vehicles persists. Given the current low BEV adoption rate, introducing BEV-exclusive lanes presents a significant opportunity to enhance traffic management. Initial simulations suggest that implementing BEV lanes could reduce the road volume ratio by 99.85%. This reduction would be particularly impactful on heavily congested road segments, where ICE vehicles significantly contribute to traffic jams.

Prioritizing the implementation of BEV lanes in high-traffic areas can also improve driving conditions for BEV owners, encouraging further adoption of these environmentally friendly vehicles. Xue et al. (2024) underscore the importance of such measures in promoting sustainable transport, particularly by providing early adopters with a smoother and more efficient driving experience, which could accelerate the transition to BEVs. By addressing congestion through targeted BEV lanes, Jakarta could enhance both traffic flow and environmental sustainability, aligning with broader urban mobility goals.

Determine The Effectiveness of The Policy

Based on simulations, the mandatory BEV policy is proven to provide a solution to reduce traffic congestion in a specific year based on the target of road service levels. The simulation is divided into two scenarios, linear growth scenario and exponential growth scenario:

a. Linear Growth Scenario

Under the Linear Growth Scenario, this policy has effectively reduced traffic congestion over specific periods. For instance, if the target is to achieve an average speed at Level C, the policy will remain effective for 16.5 years in Cluster 1, 21.4 years in Cluster 2, and 6.1 years in Cluster 3. A detailed simulation for each congestion level is provided in Table 8.

Table 8: Effective (Years) of Policy with Linear Growth Scenario

Targeted Average Speed (km/hour)	Effective (Years) of Policy in Level of Road Services With Linear Growth Scenario		
	Cluster 1	Cluster 2	Cluster 3
> 48 (Level A)	6.3	8.3	1.9
40 - 48 (Level B)	12.3	15.9	4.3
33.6 - 40 (Level C)	16.5	21.4	6.1
25.6 -33.6 (Level D)	21.8	28.1	8.2
22.4 – 25.6 (Level E)	23.9	30.8	9.1

b. Exponential Growth Scenario

In the Exponential Growth Scenario, three different growth rates are considered: a 5% growth rate (business as usual), a 10% growth rate (optimistic), and a 20% growth rate (very optimistic). Even with exponential growth, this policy has been shown to reduce traffic congestion over specific periods. For instance, if the target is to achieve an average speed at

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DOI: 10.5281/zenodo.13822937

Level C under the business-as-usual scenario, the policy will be effective for up to 11.9 years in Cluster 1, 14.4 years in Cluster 2, and 5.2 years in Cluster 3. A detailed simulation for each level is provided in Table 9.

Table 9: Effective (Years) of Policy with 5 % Exponential Growth Scenario

Targeted Average Speed (km/hour)	Effective (Years) of Policy in Level of Road Services With (5 %) Exponential Growth Scenario		
	Cluster 1	Cluster 2	Cluster 3
> 48 (Level A)	5.4	6.8	1.8
40 - 48 (Level B)	9.4	11.6	3.9
33.6 - 40 (Level C)	11.9	14.4	5.2
25.6 -33.6 (Level D)	14.6	17.4	6.8
22.4 – 25.6 (Level E)	15.6	18.5	7.3

Under the 10% growth scenario (optimistic), the policy continues to demonstrate effectiveness in reducing traffic congestion over specific time frames. For instance, if the target is to reach an average speed at Level C, the policy will be effective for up to 9.6 years in Cluster 1, 11.3 years in Cluster 2, and 4.6 years in Cluster 3. A comprehensive simulation for each level is detailed in Table 10.

Table 10: Effective (Years) of Policy with 10 % Exponential Growth Scenario

Targeted Average Speed (km/hour)	Effective (Years) of Policy in Level of Road Services With (10 %) Exponential Growth Scenario		
	Cluster 1	Cluster 2	Cluster 3
> 48 (Level A)	4.7	5.9	1.7
40 - 48 (Level B)	7.9	9.4	3.5
33.6 - 40 (Level C)	9.6	11.3	4.6
25.6 -33.6 (Level D)	11.5	13.3	5.8
22.4 – 25.6 (Level E)	12.1	14.0	6.3

Under the 20% growth scenario (very optimistic), the policy effectively reduces traffic congestion over defined periods. For example, if the target is to achieve an average speed at Level C, the policy will be effective for up to 7.2 years in Cluster 1, 8.3 years in Cluster 2, and 3.8 years in Cluster 3. A detailed simulation for each level is presented in Table 11.

Table 11: Effective (Years) of Policy with 20 % Exponential Growth Scenario

Targeted Average Speed (km/hour)	Effective (Years) of Policy in Level of Road Services With (20 %) Exponential Growth Scenario		
	Cluster 1	Cluster 2	Cluster 3
> 48 (Level A)	3.9	4.8	1.5
40 - 48 (Level B)	6.1	7.1	3.0
33.6 - 40 (Level C)	7.2	8.3	3.8
25.6 - 33.6 (Level D)	8.4	9.5	4.7
22.4 – 25.6 (Level E)	8.8	10.0	5.0

The simulations indicate that transitioning to a mandatory BEV policy is a viable alternative to the current odd-even system. The low adoption rate of electric vehicles can be attributed to the Theory of Planned Behavior, which suggests that psychological factors are crucial in influencing an individual's intention to purchase an EV. Encouraging positive perceptions of BEVs is essential (Riverso et al., 2023). Implementing a particular BEV Road Section policy could serve as a non-financial incentive to boost BEV adoption (Xue et al., 2021). However, BEV adoption faces challenges, particularly the lack of firsthand experience among potential users, which can hinder their willingness to transition from conventional vehicles. In Australia, studies have shown that providing trial opportunities can significantly boost interest in purchasing BEVs, with a 59.2% increase in consumer intent to buy following such trials (Viola, 2021). Following the implementation of the mandatory BEV policy, the Jakarta Provincial Government will have the opportunity to enhance public transportation accessibility and to educate the public about the benefits of using public transport over private vehicles.

DISCUSSION

The clustering analysis of the 25 odd-even road sections in Jakarta, utilizing the K-means, revealed three distinct clusters of road segments based on their characteristics. Each cluster reflects different levels of traffic congestion and road performance, offering a structured framework for targeted policy implementation. **Cluster 1,** representing the most congested roads, is recommended as the initial focus for implementing the mandatory BEV policy. These roads are critical in Jakarta's traffic network, and prioritizing BEV lanes here could yield significant reductions in congestion. Once the BEV policy has been successfully implemented in **Cluster 1**, extending it to **Cluster 2** and **3** is advisable. This phased approach allows for measured progress in managing traffic while promoting the adoption of BEVs across varying levels of road congestion. Policymakers can monitor the effectiveness of the initial implementation and adapt the strategy as needed when expanding the policy to less congested areas, ensuring a sustainable and scalable transition.

PCA analysis identified three key variables influencing road section clustering: regional characteristics, level of service, and the number of related sections, accounting for 80% of the data variance. Regional characteristics, based on geographic distribution, are crucial in prioritizing roads for BEV lanes. Level of service, reflecting traffic conditions like speed and congestion, highlights roads that could benefit from targeted interventions. The number of related sections indicates how interconnected a road is, with more connections leading to more complex congestion patterns requiring strategic management.

The effectiveness of the mandatory BEV policy is evaluated through simulations, which measure traffic congestion based on **average speed**, a key indicator of the **Level of Service**. The policy aims to improve road conditions to **Level C** (average speeds between **33.6 km/h and 40 km/h**), representing a moderate, manageable level of congestion that allows for relatively smooth traffic flow. Simulations indicate that introducing BEV-only lanes can significantly reduce congestion, with effectiveness lasting from **3.8 to 6.1 years**, depending on the cluster and road characteristics. Specifically, roads in **Cluster 1** (highly congested) are projected to see congestion relief for **3.8 years**, while **Cluster 2** and **Cluster 3** (moderately and lightly congested, respectively) could experience improvements for up to **6.1 years**.

ISSN 1533-9211
DOI: 10.5281/zenodo.13822937

By improving traffic conditions, this policy contributes to reducing vehicular emissions and enhances urban mobility and driving comfort for BEV users. This phased approach provides Jakarta's policymakers with a scalable strategy to address both traffic congestion and environmental goals, promoting a long-term shift towards sustainable urban transportation.

CONCLUSION

Traffic congestion on Jakarta's odd-even roads is a pressing issue requiring urgent action. Despite implementing the odd-even policy, traffic conditions have continued to deteriorate, as evidenced by the increased ICE vehicle ownership. The data suggests that the current policy framework is insufficient in managing the rising volume of vehicles, and without decisive changes, congestion will only worsen. The consequences of inaction are severe, as unchecked congestion could lead to widespread traffic stagnation, severely impacting urban mobility and the quality of life in the city. To address this growing problem, transitioning from the existing odd-even policy to a **BEV** policy is proposed as a forward-thinking solution. As an emerging technology, BEVs have low adoption rates in Jakarta, but this policy shift aims to encourage their widespread use, thereby reducing the number of ICE vehicles on the road. By designating specific roads for BEVs only, the policy would alleviate congestion and accelerate the adoption of environmentally friendly vehicles (Ramachandaran et al., 2023).

The mandatory BEV policy aligns with global trends in sustainable urban transport, aiming to reduce traffic and pollution. It also enhances the social status of BEV ownership, making it a desirable choice. In a society where vehicle ownership reflects prestige, exclusive road access for BEV users can drive adoption. This policy offers Jakarta residents two options: embrace BEV technology or continue with conventional vehicles. This choice presents challenges, such as the upfront cost of BEVs and uncertainties about charging infrastructure and maintenance (Woo et al., 2022). However, for those who switch, the long-term benefits, including environmental impact and access to less congested roads, are substantial. Alternatively, citizens may opt for public transportation to avoid BEV-related costs. As Jakarta's public transit system continues to improve, the BEV policy could indirectly increase public transport use among those not ready to adopt BEVs.

The introduction of the mandatory BEV policy marks a decisive step towards **sustainable urban mobility** in Jakarta. While the transition from ICE vehicles to BEVs will not happen overnight, the policy creates a framework for gradual, measurable progress. By prioritizing road sections with high congestion levels for the initial phase of the BEV policy, the city can target its efforts where they are most needed, creating immediate improvements in traffic flow and air quality. Over time, as adoption rates increase and BEV infrastructure improves, the policy can be expanded to other areas, ultimately contributing to a cleaner, more efficient urban transportation system.

Acknowledgment

The authors would like to express their deepest gratitude to the Jakarta Provincial Government for providing supporting data in this research on the characteristics of odd-even roads.

ISSN 1533-9211

DOI: 10.5281/zenodo.13822937

Declaration of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper. All research was conducted independently, and no funding or sponsorship from any commercial entity, organization, or individual was provided that could influence the findings, interpretations, or conclusions presented in this study. The authors confirm that the content of this paper is original and has not been submitted for publication elsewhere. Any materials or data used in this research were obtained ethically and transparently per all relevant regulations and guidelines.

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