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Spatial Analysis of Potential Battery Swapping Station Locations for Ride Hailing Services Using Geographic Information System

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tery Swapping Station (BSS); Geographic Information System (GIS); Kernel Density Estimation (KDE); Nearest Neighbor Index (NNI); Ride-Hailing

Abstract

This study addresses the growing need for sustainable urban transportation infrastructure through the optimization of Battery Swapping Station (BSS) locations for electric motorcycles used in ride-hailing services in South Jakarta, Indonesia. The rapid growth of electric vehicle adoption has increased the importance of accessible and efficient energy replenishment systems, particularly for ride-hailing drivers with high mobility and operational intensity. However, the limited availability and uneven distribution of existing battery swapping infrastructure continue to hinder broader adoption of electric motorcycles. Therefore, this study aims to identify strategic locations for KYMCO iONEX Battery Swapping Stations using a Geographic Information System (GIS)-based spatial analysis approach. The research employed a quantitative spatial decision support framework integrating Origin-Destination mobility data from ride-hailing drivers, minimarket retail infrastructure data, Kernel Density Estimation (KDE), Nearest Neighbor Index (NNI), and spatial overlay analysis. The findings reveal that demand for battery swapping services is highly concentrated in the north-central commercial corridors of South Jakarta, particularly in Kebayoran Baru and Setia Budi. The analysis identified ten high-priority candidate locations, with Indomaret Point Halte CSW achieving the highest demand potential score. The study concludes that BSS deployment should prioritize maximum demand capture rather than maximum geographic coverage. Integrating battery swapping facilities with high-frequency retail networks and transit-oriented development areas can significantly improve accessibility, operational efficiency, and the sustainability of urban electric mobility systems.

INTRODUCTION

The transportation sector is a primary contributor to global greenhouse gas emissions, with road transport accounting for approximately 91% of total emissions in Indonesia's transportation sector. In major urban areas like Jakarta, the dominance of conventional internal combustion engine (ICE) motorcycles, comprising nearly 70% of national transportation modes has exacerbated air pollution, contributing significantly to PM 2.5 concentrations (Indonesia Sustainable Mobility Outlook (ISMO), 2025). To mitigate these environmental impacts, the Indonesian government has targeted the production of 13 million electric motorcycles by 2030 through (Presidential Regulation, 2023).

A critical segment for electrification is the ride-hailing industry. In Indonesia, the market exceeds 88 million users, supported by over 4 million active drivers, the majority of whom operate two-wheelers. While electric motorcycles (e-motorcycles) offer up to 68% savings in operational costs compared to ICE vehicles, their adoption among ride-hailing drivers remains limited (Fenno, n.d.; Loo, 2024; Martin, 2020). The primary barriers are "range anxiety" and the scarcity of charging or swapping infrastructure. Unlike private users, ride-hailing drivers exhibit high mobility (averaging 70–90 km/day) and require rapid energy replenishment to minimize downtime (Patdono Suwignjo, et al, 2023).

Battery Swap Station (BSS) provides a viable solution by reducing the replenishment time from hours (via charging) to seconds. However, BSS deployment in Indonesia is currently driven by private investment through partnership schemes, making optimal site selection a financial necessity to ensure high utilization rates (Asa, 2025; Rohman et al., 2025; Steelyana et al., 2024). Minimarket networks, such as Indomaret and Alfamart, present ideal candidate locations due to their ubiquitous presence over 43,000 outlets nationwide 24-hour accessibility, and existing electrical infrastructure. One of the electrical infrastructures in Indonesia that is mostly used by drivers of ride hailing is the KYMCO iONEX Battery Exchange System (BSS) (Martono et al., 2025; Saputra et al., 2023).

KYMCO, a leading global company in the automotive industry, particularly in two-wheeled electric vehicles, continues to innovate to improve customer convenience and operational efficiency. One of its flagship technologies is the KYMCO iONEX Battery Swapping System (BSS), an integrated battery exchange ecosystem designed to support sustainable urban mobility (Comelli, 2020; Mohanty et al., 2025). Compared to conventional charging systems, the iONEX BSS provides several advantages, such as a fast and practical battery swapping process without requiring QR code scanning or manual door operations, making it more efficient for high-mobility users such as ride-hailing drivers. In addition, the iONEX ecosystem is considered suitable for urban transportation because it reduces charging waiting time and supports continuous vehicle operation (Aldhanhani et al., 2024; Borgosano et al., 2024; Jawad & Liu, 2020).

The selection of KYMCO iONEX BSS in this study is important because battery swapping technology has significant potential to support the operational sustainability of electric motorcycles used in ride-hailing services. However, based on primary survey data collected from ride-hailing drivers using KYMCO electric motorcycles, many drivers reported difficulties in locating the nearest KYMCO iONEX BSS during daily operations. This issue affects operational efficiency, travel continuity, and user convenience, especially during peak working hours. Currently, there are only 10 KYMCO iONEX BSS locations available in South Jakarta, indicating that the existing infrastructure coverage is still limited compared to the mobility demand of ride-hailing drivers. Therefore, identifying potential strategic locations for additional battery swapping stations is essential to improve accessibility, reduce travel distance to stations, and support the wider adoption of electric motorcycles in urban transportation systems.

Ride-hailing services represent one of the most important segments for electric motorcycle adoption because drivers operate intensively, travel long daily distances, and require minimal downtime. The manuscript notes that Indonesia's ride-hailing market exceeds 88 million users and is supported by more than 4 million active drivers, most of whom use two-wheelers. It also explains that electric motorcycles can reduce operational costs by up to 68% compared with internal combustion engine vehicles, yet adoption remains constrained by range anxiety and limited replenishment infrastructure. This condition shows that the economic advantage of electric motorcycles will not automatically lead to adoption unless infrastructure is spatially aligned with real driver mobility patterns.

Battery Swapping Stations offer a practical solution because they can reduce energy replenishment time from hours to seconds. This advantage is especially important for ride-hailing drivers who cannot afford long charging periods during productive working hours. Recent research on Indonesian ride-sharing platforms found that electric vehicles can provide operational benefits for platform-based mobility, but infrastructure readiness remains a key condition for implementation. Similarly, research on electric motorcycle adoption in Indonesia highlights that rapid replenishment is more achievable through battery swapping than conventional charging, although availability and compatibility remain challenges.

The specific issue addressed in this study is the limited and uneven availability of KYMCO iONEX Battery Swapping Stations in South Jakarta. According to the manuscript, only 10 KYMCO iONEX BSS locations currently serve the area, while ride-hailing drivers using KYMCO electric motorcycles report difficulty finding nearby stations during daily operations. This problem affects travel continuity, driver productivity, and user confidence in electric motorcycles. In dense urban districts such as South Jakarta, infrastructure gaps are not simply a matter of insufficient station numbers, but also of whether stations are located near actual origin-destination hotspots, transit corridors, and retail nodes that drivers frequently pass.

Previous studies have examined battery swapping and charging infrastructure location from various methodological perspectives. Zeng et al. developed a data-driven framework for battery swapping station location selection, emphasizing the importance of demand information in infrastructure planning. On-Ouen et al. proposed a GIS-based and multi-objective approach for motorcycle BSS location selection using Euclidean distance, K-NN, AHP, and road infrastructure data. Ma et al. also proposed demand-oriented planning for battery swap station siting to meet rapid energy replenishment needs. These studies demonstrate that spatial planning is essential for BSS deployment, but local evidence for Indonesian ride-hailing drivers and retail-based BSS integration remains limited.

The research gap lies in the limited integration of ride-hailing origin-destination mobility data, existing KYMCO iONEX infrastructure, and minimarket-based candidate locations within one spatial decision framework. Many infrastructure studies focus on theoretical coverage, general charging demand, or citywide facility optimization, while fewer studies examine how high-frequency retail networks such as Indomaret, Alfamart, Alfamidi, and Circle K can function as practical nodes for battery swapping deployment. The attached manuscript addresses this gap by combining GIS, Kernel Density Estimation, Nearest Neighbor Index, spatial overlay, and candidate ranking to identify high-potential BSS locations in South Jakarta.

The urgency of this research is strengthened by the mismatch between Indonesia's ambitious electric motorcycle targets and the current infrastructure limitations experienced by high-mobility users. Without strategically located BSS, ride-hailing drivers may continue to perceive electric motorcycles as risky, inefficient, or less reliable than conventional motorcycles. Poorly located stations may also create low utilization, weak investment returns, and inefficient public-private infrastructure deployment. Therefore, evidence-based site selection is necessary to ensure that BSS expansion supports both environmental goals and the economic needs of ride-hailing drivers.

The novelty of this research lies in its focus on demand-capture rather than simple geographic coverage. Instead of distributing stations evenly across South Jakarta, the study identifies where ride-hailing trip origins and destinations actually concentrate, then links those demand hotspots with accessible retail infrastructure. The manuscript's results show that the top 10 recommended BSS locations are concentrated in Kebayoran Baru, especially around CSW, Melawai, and Blok M, indicating that dense clustering may be functionally necessary in high-demand corridors. This offers a more realistic planning logic for urban electric motorcycle ecosystems, where utilization, redundancy, and proximity to mobility hubs are more important than equal spatial distribution.

Therefore, this study aims to identify strategic potential locations for KYMCO iONEX Battery Swapping Stations for ride-hailing services in South Jakarta using a Geographic Information System-based spatial decision approach. The research contributes theoretically by enriching the literature on EV infrastructure planning, GIS-based mobility analysis, and battery swapping location optimization in emerging urban contexts. Practically, it benefits EV infrastructure providers, ride-hailing platforms, retail partners, and policymakers by offering data-driven recommendations for station deployment. The study also supports broader environmental and transport policy goals by helping accelerate electric motorcycle adoption through infrastructure that is closer to real user demand, operationally efficient, and spatially responsive to urban mobility patterns.

METHOD

Data Acquisition and Spatial Pre-processing

The research framework employed a spatial decision support system to identify optimal locations for BSS. This study employs a GIS-based quantitative approach to analyze the spatial relationship between urban mobility demand and retail accessibility in South Jakarta. The approach integrates demand-side geospatial data with existing retail infrastructure to prioritize sites with the highest service potential. The framework begins with the integration of multi-source geospatial datasets, encompassing administrative boundaries, existing infrastructure, and potential retailer locations. Primary spatial data for administrative boundary were obtained in vector format, while KYMCO iONEX BSS and retailer points (Indomaret, Alfamart, Alfamidi, and Circle K) were consolidated into a spatial database. KYMCO, a leading global company in the automotive industry, particularly in two-wheeled vehicles, continues to innovate to ensure customer satisfaction. One of its flagship products is the KYMCO iONEX BSS. This BSS offers several advantages, including a quick and easy battery swap process without the need for QR scanning or opening and closing doors. Based on primary data from driver of ride hailing, users of KYMCO vehicle have difficulty finding the nearest KYMCO iONEX BSS in daily operational. Currently, there are only 10 KYMCO iONEX BSS in South Jakarta. All datasets were standardized to the World Geodetic System 1984 (WGS84) coordinate system, corresponding to EPSG:4326, to ensure spatial alignment during the overlay process. The primary dataset consists of point-based geospatial features categorized into three distinct layers:

- Demand Points (Origin-Destination Data): A high-resolution dataset representing localized demand clusters derived from movement patterns. The total number of trips by historical data of 100 ride-hailing drivers are 1089 trips.
- Candidate Locations (Retail Infrastructure): Geospatial coordinates of major minimarket franchises (*Indomaret, Alfamart, Alfamidi,* and *Circle K*) in South Jakarta, serving as the primary nodes for BSS integration (as shown in Figure 1). The candidate locations for BSS integration consist of point-based spatial data representing four major minimarket franchises within the South Jakarta administrative area. As illustrated in Figure 1 below, the dataset includes a total of 450 retail nodes, categorized by brand: Indomaret (280 sites), Alfamart (64 sites), Alfamidi (93 sites), and Circle K (13 sites). The spatial distribution of these nodes is non-uniform, reflecting the urban density and commercial zoning of the district. A high concentration of retail points is observed in the north-central corridors, particularly within Kebayoran Baru, Setia Budi, and Mampang Prapatan, which align with the primary business districts. In contrast, the southern and peripheral regions, such as Jagakarsa and Pesanggrahan, exhibit a more dispersed pattern, primarily serving residential demand.

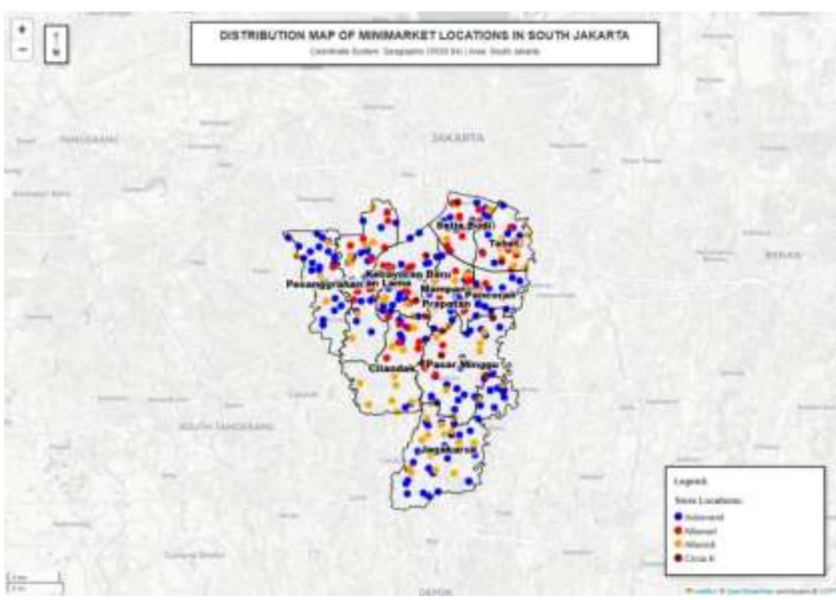


Figure 1. Distribution Map of Minimarket Locations in South Jakarta

- **Existing Infrastructure:** Current KYMCO iONEX BSS locations used for spatial gap analysis and overlay comparison. Table 1 below shows the existing location of BSS IONEX, with the total of 10 stations distributed within South Jakarta.

Table 1. IONEX Stations Location

No.	IONEX Station	Sub-district	Coordinate
1	SPBU COCO Kemang 31.127.01	Mampang Prapatan	-6.2735288,106.8186868
2	SPBU COCO Kuningan 31.129.02	Setiabudi	-6.2285845,106.833711
3	SPBU COCO M.T Haryono 31.128.02	Tebet	-6.2425144,106.8523814
4	Uma Kost RKBM Gandaria	Kebayoran Baru	-6.2391303,106.7854266
5	Rukita KLS Pasar Minggu - Kost Coliving	Pasar Minggu	-6.3001538,106.839819
6	Rukita Pacific Setiabudi - Kost Coliving	Setiabudi	-6.2092918,106.825873
7	PT PLN (Persero) UP3 Lenteng Agung	Pancoran	-6.2541118,106.8355412
8	PLN UP3 Bulungan	Kebayoran Baru	-6.2395283,106.797939
9	KFC Ciledug Petukangan	Pesanggrahan	-6.2367824,106.7505364
10	KFC Kemang Timur	Pasar Minggu	-6.2741833,106.8210871

Spatial Demand Modeling (Heatmap Generation)

To evaluate the spatial distribution of demand, a Kernel Density Estimation (KDE) or a weighted sum within a fixed radius was applied to the Origin-Destination (OD) dataset. This process transforms discrete points into a continuous demand surface, allowing for the identification of high-density hotspots. The density $f(s)$ at a specific location s is estimated using the following kernel function (Gao & Zhong, 2010; Lasocki, 2021)

$$f(s) = \sum_{i=1}^{n} \frac{1}{h^2} K\left(\frac{d_{is}}{h}\right) \quad (1)$$

Where:

- n is the total number of demand points within the search radius.
- d_{is} is the Euclidean distance between the target location s and the demand point i.
- k is the kernel weighting function, which assigns higher influence to demand points closer to the center of the search radius.
- h is the search radius, calibrated to 1.9 km to align with the operational service range of a single swap station. 1.9 km were obtained through Nearest Neighbor Index (NNI). This is to evaluate the spatial distribution of existing infrastructure and identify competitive patterns within the study area. The distribution pattern is determined by the ratio of the observed mean distance between nearest neighbors to the expected mean distance for a random distribution.

Given the total area of South Jakarta A = 141,37 km^2 (Pemerintah Provinsi DKI Jakarta, 2023) and the number of existing BSS infrastructure points (N = 10), the spatial density (λ) is first established as $\lambda = \frac{N}{A}$. The Observed Mean Distance ($\bar{d}_{obs}$) is calculated by averaging the distances from each point to its nearest neighbor:

$$\bar{d}_{obs} = \frac{\sum_{i=1}^{n} d_i}{N} \quad (2)$$

In this study, the observed mean distance was found to be 1,697 km. This value represents the actual average proximity between existing facilities. To determine if this distance indicates a specific pattern, it is compared to the Expected Mean Distance ($\bar{d}_{exp}$), which serves as the benchmark for a perfectly random distribution (Poisson process). The expected distance is calculated as:

$$\bar{d}_{exp} = \frac{1}{2\sqrt{\lambda}} = \frac{1}{2\sqrt{N/A}} \quad (3)$$

Based on the study area's parameters, the expected mean distance was calculated at 1,909 km. This theoretical value indicates that if the facilities were placed randomly across South Jakarta, they would, on average, be roughly 1.91 km apart. Finally, the Nearest Neighbor Index (R) is derived as the ratio between the two:

$$R = \frac{\bar{d}_{obs}}{\bar{d}_{exp}} \quad (4)$$

The Nearest Neighbor Index (NNI), introduced by Clark and Evans in 1954, is used to compare the observed distance between neighboring points with the distance expected under a random spatial distribution. This method calculates the average distance from each point to its closest neighboring point. The resulting NNI value is then used to identify spatial distribution patterns. An NNI value lower than 1.0 indicates that the observed average distance is smaller than the expected random distance, suggesting a clustered distribution pattern. In contrast, values close to or greater than 1.0 indicate a more random or dispersed spatial arrangement (Clark & Evans, 1954). In this study, the analysis was conducted using Python based.

The resulting R score of 0.889 serves as the primary indicator for spatial interpretation. According to NNI theory, an R value of 1 indicates a random distribution, $R > 1$ suggests dispersion or competition-based spacing, and $R < 1$ signifies a clustered pattern. The calculated score of 0.889 ($R < 1$) confirms that the existing infrastructure in South Jakarta exhibits a clustered spatial distribution, indicating high competition and a tendency for facilities to concentrate in specific high-demand corridors rather than being evenly spread throughout the district.

Data Normalization

The resulting density values for both Origin and Destination layers are normalized using Min-Max Normalization (also known as feature scaling). Min-Max normalization removes the impact of inconsistent ranges among features, making datasets more uniform and improving the interpretability of data processing while reducing computational complexity and avoiding numerical issues like precision loss (Manikandan et al., 2013; Muhammad Ali, 2022). Min-Max normalization can also be used to sanitize data for privacy preservation during data mining processes, ensuring both accuracy and confidentiality (Manikandan et al., 2013).

This method is applied to the density values of the Origin and Destination layers to scale them into a uniform range of 0 to 1 to ensure a uniform demand index (P_c) across the study area (Trung, 2022):

$$P_c = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (5)$$

Where:

- P_c is the normalized demand index at point i.
- X_i is the original density value at point i.
- X_{min} is the minimum density value within the dataset.
- X_{max} is the minimum density value within the dataset.

Candidate scoring and ranking

The candidate scoring and ranking phase follows a systematic four-step workflow, starting from spatial attribution, score normalization, multi-criteria filtering, and priority indexing to transform continuous demand surfaces into actionable infrastructure recommendations. The prioritization process begins with a spatial intersection (spatial join) between the discrete candidate retail nodes and the continuous demand surfaces generated in the previous stage. This step extracts the localized demand intensity for both Origin (*O*) and Destination *(D)* layers at each minimarket's coordinate, effectively assigning a raw potential value to each store based on its proximity to high-density movement clusters. To ensure that the final recommendations are statistically comparable and easily interpretable for decision-makers, these raw values are subjected to Min-Max Normalization. This mathematical transformation scales the potential scores into a standardized range of [0, 1] using Equation 5.

Once normalized, the candidates are filtered to exclude sites that overlap with existing IONEX infrastructure, ensuring the expansion of the network's service area rather than redundant saturation. The remaining candidates are then sorted in descending order based on their P_c (normalized potential score) values. The Top-10 Strategic Recommendations are identified as the highest-ranking nodes that demonstrate the greatest capacity to capture vehicle traffic while maintaining spatial efficiency within the South Jakarta district. This hierarchical approach ensures that infrastructure investment is directed toward locations with the highest verified demand-to-accessibility ratio. Top-N recommendation systems aim to provide a concise list of items that are most relevant to the user. A smaller value of N, such as 10, ensures that the list is manageable and actionable for users, improving their experience by avoiding information overload (Xu et al., 2024)

RESULTS AND DISCUSSION

Spatial Heatmap Distribution of Origin - Destination Trips

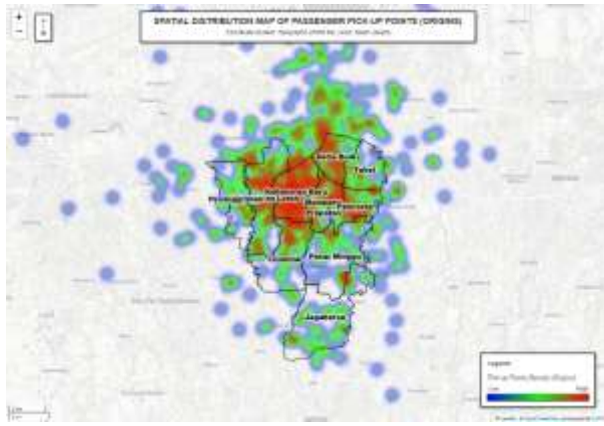


Figure 2. Spatial Heatmap Distribution of Origin

The spatial intensity of passenger pickup points (Origin) is illustrated in Figure 2. The results indicate a non-uniform distribution of demand across South Jakarta, characterized by a primary spatial epicenter and several secondary clusters. The highest demand density (represented by the red-core zones) is concentrated within the north-central administrative districts of Setia Budi, Kebayoran Baru, and Mampang Prapatan. High-to-moderate demand (yellow and green gradients) extends eastward into Tebet and Pancoran, and southward towards Pasar Minggu. Minimal trip generation (blue-shaded areas) is observed in the southernmost district of Jagakarsa and the westernmost district of Pesanggrahan, where demand appears scattered rather than clustered.

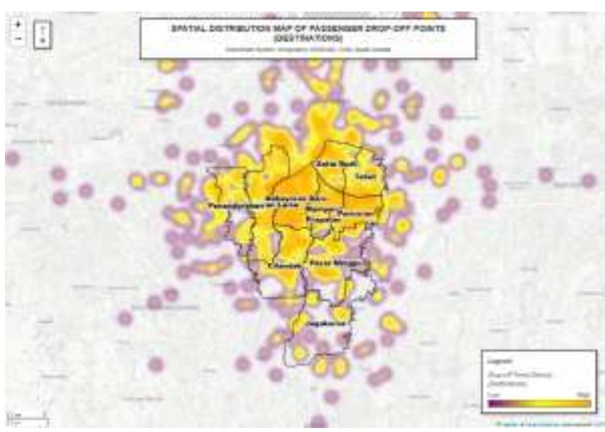


Figure 3. Spatial Heatmap Distribution of Destination

The distribution of passenger drop-off points (Destination) is presented in Figure 3. The spatial footprint of destination intensity exhibits a high degree of congruence with the origin patterns. The peaks destination intensity (bright yellow clusters) is located predominantly in the Kebayoran Baru and Setia Budi districts. A comparison between the Origin and Destination heatmaps reveals a significant overlap in high-intensity zones. Both pickup and drop-off activities are maximized within the same central commercial corridors. While the destination hotspots are more localized than the origin clusters, they maintain a consistent presence along the north-south axis of the district, specifically following the major road networks connecting central business areas.

The results from both heatmaps confirm that the demand for movement and consequently the demand for energy replenishment via BSS is not evenly distributed. The data shows a clear north-central concentration of trip activity, with the lowest activity levels recorded in the southern residential fringes of the study area. Following the spatial demand modeling, the candidate retail nodes were evaluated through spatial attribution and statistical ranking.

Candidate scoring and ranking

The integration of the normalized demand surfaces with the candidate retail locations yielded a heterogeneous distribution of potential scores across the study area. The spatial overlay analysis was performed to visualize the theoretical service area of each candidate retailer brand across the South Jakarta study area. A fixed coverage radius of 1.909 km was applied to each individual retail node, representing the operational buffer within which demand points can be effectively serviced. The results below illustrate a high degree of spatial reach for major retails, particularly Indomaret and Alfamart, whose dense network of locations creates extensively overlapping service buffers that cover nearly the entire administrative extent of South Jakarta. In contrast, the spatial footprint for Alfamidi shows a more distributed but less saturated pattern, while Circle K exhibits the most localized coverage, with buffers primarily concentrated in high-activity north-central districts such as Setia Budi and Kebayoran Baru. This overlay against destination points highlights specific geographic clusters where the concentration of retail infrastructure aligns with high-intensity demand, providing a baseline for the subsequent ranking and site prioritization process.

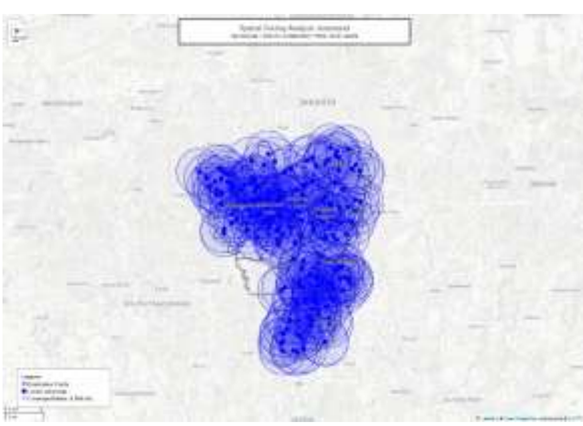


Figure 4. Spatial Overlay Analysis-Indomaret

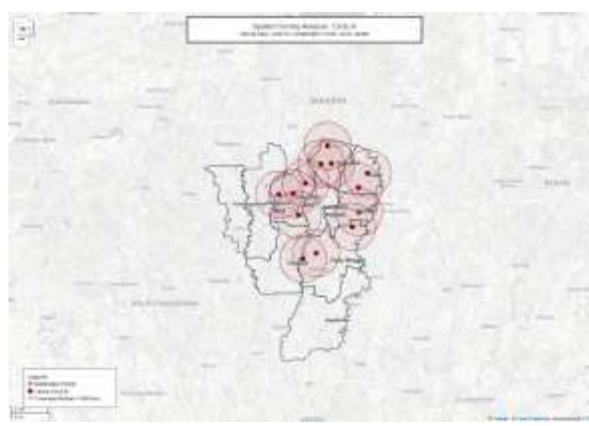
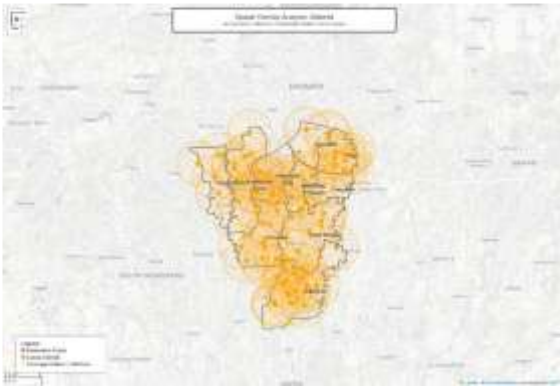


Figure 5. Spatial Overlay Analysis-Circle K



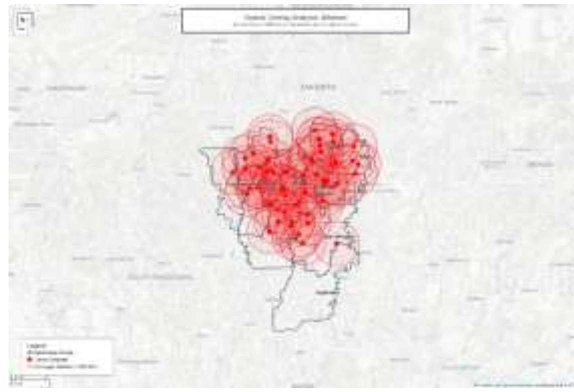


Figure 6. Spatial Overlay Analysis-Alfamidi **Figure 7. Spatial Overlay Analysis-Alfamart**

The final stage of the spatial decision support workflow involved the identification and prioritization of the most viable retail nodes for BSS integration. A total of 10 primary locations were identified as high-priority sites for the implementation of BSS. The map below visualizes the culmination of the geospatial workflow, highlighting the Top 10 recommended retail nodes in relation to the existing KYMCO iONEX infrastructure. The KYMCO iONEX stations marked by green bolt icons demonstrate a clear preference for the north and central administrative corridors. While the stations provide broad regional coverage, there is a visible saturation in districts characterized by high commercial density and transit activity.

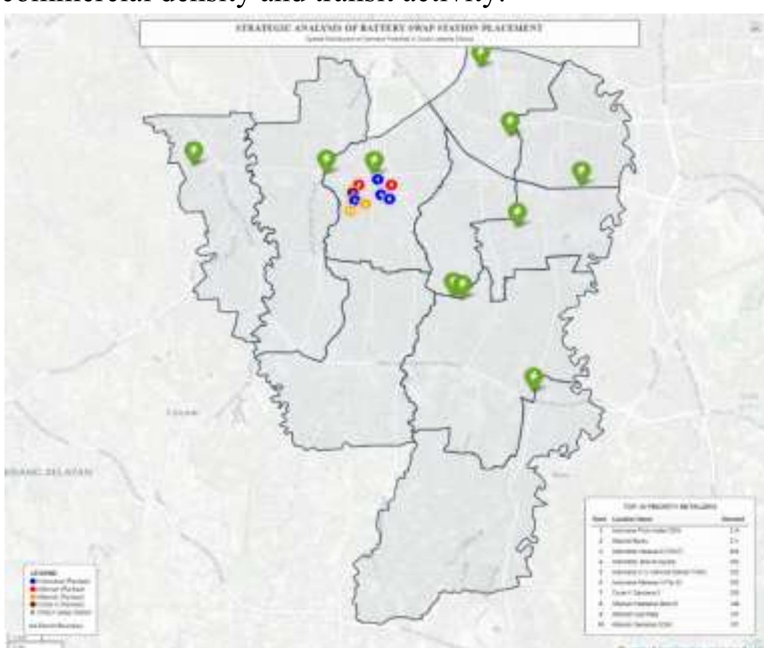


Figure 8. Strategic Analysis of BSS Placement

The mapping results in Figure 8 reveal an extreme geographical concentration of high-potential sites. All ten recommended locations are situated exclusively within the Kebayoran Baru, forming a dense cluster in the north-central region of South Jakarta. This spatial pattern indicates that the highest values of trip origin and destination intensity converge within this specific commercial and transit hub. The clustering effect suggests that the demand for energy replenishment is not merely high but hyper-localized, justifying a high-density deployment of swap stations within a limited geographical radius to serve the urban mobility core.

The following table 1 summarizes the highest-ranking candidate locations based on their aggregate demand potential (P_c). The scores represent the captured intensity from the normalized Origin and Destination surfaces within a 1.9 km service radius.

Table 2. Ranking Candidate Locations of BSS

Rank	Retailer Location	Demand Potential Score (point)
1	Indomaret Point Halte CSW	214
2	Alfamidi Barito	211
3	Indomaret Melawai 8 {TKD7}	204
4	Indomaret, Blok M Square	202
5	Indomaret K.H. Achmad Dahlan TWXJ	202
6	Indomaret Melawai IV No 52	202
7	Circle K Gandaria 2	200
8	Alfamart Faletehan Blok M	198
9	Alfamart Kyai Maja	197
10	Alfamidi Gandaria SC99	197

As shown in the priority retailers table, the demand potential scores range from a maximum of 214 to a minimum of 197. Indomaret Point Halte CSW occupies the top rank, representing the point of maximum demand interception in the study area. It is followed closely by Alfamidi Barito (Rank 2) with a score of 211. The relatively narrow range between the first and tenth-ranked sites a difference of only 17 units, emphasizes a competitive environment where multiple retail locations offer similarly high utility for BSS users. This quantitative consistency reinforces the validity of the Kebayoran Baru cluster as the primary strategic implementation zone.

In summary, the spatial decision-making framework successfully identified ten high-priority retail nodes, all of which are geographically concentrated within the Kebayoran Baru district. The high degree of score uniformity among these top-ranked sites, varying by less than 10% statistically validates this area as the primary strategic corridor for BSS implementation. These quantitative findings provide the empirical baseline for the following discussion, which examines the underlying socio-technical factors, such as transit-oriented development (TOD) and spatial agglomeration, that necessitate such a clustered infrastructure strategy in South Jakarta.

The top-ranked location, Indomaret Point Halte CSW (Rank 1, Demand: 214), represents the most strategic node in the study area. Its high score is directly correlated with its proximity to the ASEAN/CSW Transit Hub, which integrates the TransJakarta BRT and the Jakarta MRT. Its location in Kebayoran Baru, which was originally planned as a satellite city in the 1950s and has undergone significant transformation, including gentrification and shifts from residential to commercial land use (Ratriananda, 2021). From a transportation engineering perspective, placing a BSS at this node maximizes the capture rate of users transitioning between public transit and last-mile electric two-wheelers (Ashri Prawesthi & Yola, 2022). This synergy between BSS infrastructure and TOD hubs is critical for optimizing urban energy replenishment networks.

The results indicate a notable spatial concentration of high-priority sites within the Melawai and Blok M commercial zones (Figure 9). Specifically, the locations designated as Rank 3, Rank 4, Rank 6, and Rank 8 are situated within a 500-meter radius. This spatial agglomeration is consistent with the previously calculated Nearest Neighbor Index (R = 0.889), which identifies the Blok M precinct as a primary spatial trip attractor within the study area. As a central component of the Jakarta MRT network, the Blok M station facilitates high-volume transit between South Jakarta and the broader metropolitan region, influencing localized movement patterns and urban density (Santosa & Basuki, 2003; Sitanggang et al., 2020). The spatial alignment of 50% of the top-ranked BSS candidate sites with this transit hub suggests a strategic correlation with intermodal transfer points. These stations function as infrastructure for managing first-mile and last-mile connectivity. By situating battery swapping facilities at high-frequency retail nodes within the immediate vicinity of the MRT hub, the network supports the integration of mass transit with zero-emission micro-mobility. This configuration is designed to address localized demand peaks generated by transit commuters, providing the necessary energy capacity to support the high density of electric two-wheelers operating within this TOD corridor.

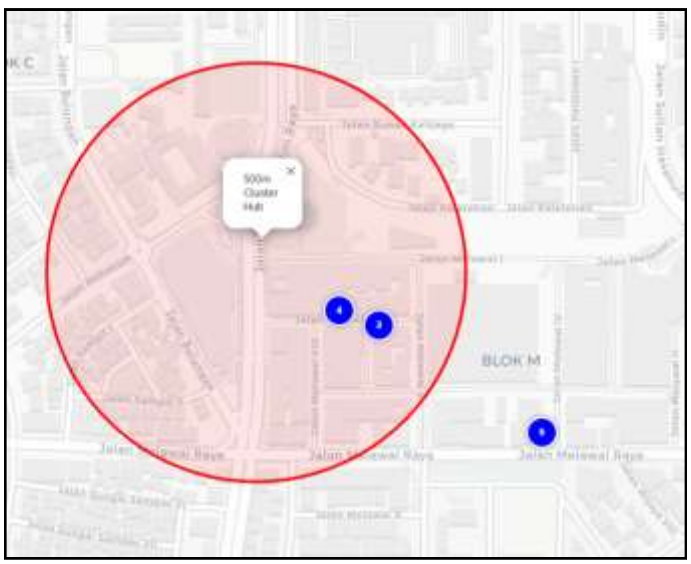


Figure 9. BSS Candidate Location in Blok M Zone

Beyond the central hub, the recommendations follow major arterial and collector roads, which are essential for intercepting "en-route" demand. Western Corridor such as Alfamidi Barito (Rank 2) and Alfamidi Gandaria SC99 (Rank 10) capture traffic along the Barito-Gandaria axis, serving as a gateway for users traveling from residential areas in the west toward the central business districts. North-South Axis: Indomaret K.H. Achmad Dahlan (Rank 5) and Circle K Gandaria 2 (Rank 7) are strategically positioned along high-volume corridors that link Kebayoran Baru to the southern residential districts of Cilandak and Pasar Minggu.

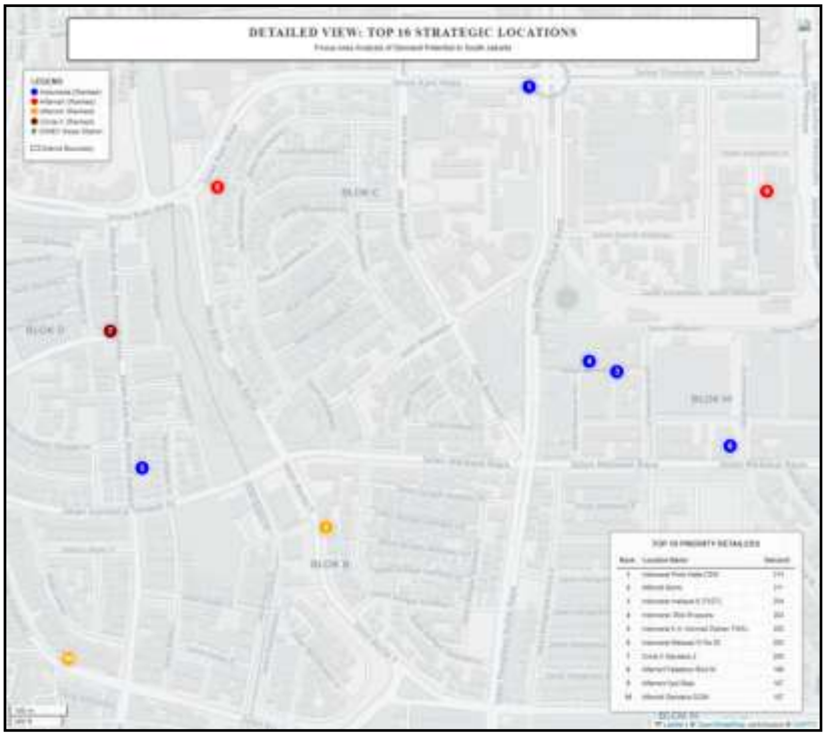


Figure 10. Top-10 Strategic Candidate Location of BSS

The distribution of the top ten sites across retail brands in Figure 11 provides insights for corporate partnership strategies. Indomaret dominates the priority list, capturing 50% (5 out of 10) of the top spots, including the highest-ranking node. Alfamidi and Alfamart each contribute 20%, while Circle K represents 10%. This brand distribution indicates that a partnership with Indomaret would provide IONEX with the most immediate access to high-demand urban nodes in South Jakarta, though a multi-brand strategy (incorporating Alfamidi at Rank 2) would ensure broader spatial redundancy across the district. The decision to place new stations in proximity to existing ones and to each other is justified by three primary factors:

1. Agglomeration Economies and Hub Reliability

   The intense clustering within a 500-meter radius in the Melawai area (Ranks 3, 4, 6, and 8) creates an infrastructure hub effect. In high-intensity demand zones, the reliability of a BSS network depends on battery availability during peak hours. By clustering stations, the network reduces the risk of service failure; if one station reaches zero battery inventory, users can access an alternative node within a negligible travel distance. This redundancy is critical for maintaining user trust in electric vehicle (EV) ecosystems.

2. Peak Load Management vs Geometric Coverage

   The Origin and Destination heatmaps (Figure 1 and Figure 2) clearly demonstrate that trip activity is not linear or evenly spread. A single station in a low-demand area like Jagakarsa might provide high spatial coverage but yield a low utilization rate. Conversely, the Kebayoran Baru cluster serves a peak load that likely exceeds the capacity of the current IONEX network.

Therefore, the proposed Top 10 sites represent a capacity expansion rather than a redundant duplication.

3. Strategic Retail Synergies

The preference for high-ranking nodes such as Indomaret Point Halte CSW (Rank 1) and Alfamidi Barito (Rank 2) highlights the importance of leveraging existing retail footfall. Unlike standalone stations, BSS units integrated with minimarkets benefit from established power grids, security, and the "trip chaining" behavior of users who may shop while swapping batteries. The competition between brands (Indomaret, Alfamart, Alfamidi, and Circle K) ensures that the BSS network is embedded in the most accessible and socially familiar nodes of the urban fabric.

The results suggest that policy-makers and EV infrastructure providers should shift their focus from Maximum Coverage to Maximum Demand Capture. The clustering of stations in South Jakarta's commercial heart reflects the real-world movement of commuters and delivery services. To prevent market cannibalization, future expansion should use the 1.9 km service radius not just as a limit for service, but as a parameter for calculating the volumetric demand that a single node can handle before a secondary station is required in its immediate vicinity.

CONCLUSION

This research successfully implemented a Geospatial Decision Support System (GDSS) to optimize Battery Swap Station (BSS) placement in South Jakarta by integrating mobility patterns with existing retail infrastructure, revealing that trip generation and attraction are highly localized within north-central commercial corridors of Kebayoran Baru and Setia Budi, where BSS infrastructure should be prioritized to maximize capture of short-to-medium distance urban journeys. Statistical evaluation of the existing IONEX network yielded a Nearest Neighbor Index of $R = 0.889$, confirming clustered spatial distribution, which this study demonstrates is functionally necessary in high-density areas to manage peak loads rather than being redundant evidenced by the identification of Indomaret Point Halte CSW as the highest-ranking node (Demand Potential: 214) and a sub-500m cluster in the Melawai-Blok M area functioning as a collective "power hub" ensuring battery availability during peak capacity. The findings demonstrate that transitioning to electric mobility in dense urban environments requires shifting from maximum geographic coverage to targeted demand capture by leveraging high-frequency retail points (Indomaret, Alfamidi, Alfamart, and Circle K) to deploy resilient, high-capacity BSS networks aligned with actual urban movement patterns. Future research should transition from static spatial planning to operational resilience modeling by integrating real-time mobility data with power grid capacity analysis to manage localized loads from clustered infrastructure, while expanding the framework to include multi-objective optimization incorporating dynamic user behavior, queue management systems, renewable energy integration through solar-powered hubs, and temporal demand fluctuation modeling to ensure the long-term scalability, systemic sustainability, and operational efficiency of urban electric vehicle ecosystems.

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