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The Anatomy of Bus Stops

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Khazanah Research Institute

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Summary

- **Bus stop infrastructure across Greater KL is structurally inadequate.** A computer vision assessment of more than 5,000 bus stop images shows that most stops lack essential amenities such as shelters, benches, lighting, and clear signage. These deficiencies are widespread, with little to no moderate-high quality bus stop amenities distributed across geographical clusters**.**

- **Amenity gaps meaningfully affect perceived waiting time, safety and the decision to use public transport.** Evidence from the literature suggests that poor waiting environments increase perceived wait durations on the part of the rider. This reduces feelings of safety, and discourage use, particularly among groups that are more sensitive to how safety and comfort is experienced.

- **Two policy interventions offer immediate improvements.** A national bus stop design standard would establish minimum requirements for safety, accessibility and comfort, guiding bus stop upgrades across jurisdictions. Real-time arrival information systems, through countdown displays reduce uncertainty and significantly improve perceived waiting time even when bus frequency remains unchanged.

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1. Introduction

Commuters usually form their judgement about public transport long before they step onto a bus. The decision can sometimes begin at the bus stop. It begins with whether there is shade from the hot weather or from rain, whether the area feels visible and safe, whether there are signals that indicate when a bus is expected to arrive. Where these attributes are missing, commuters can reasonably expect their journey to be problematic even before the vehicle even enters the frame. Across Greater Kuala Lumpur (KL), many bus stops do not meet these basic thresholds. Some provide reasonable shelter and lighting, but many others are exposed, poorly marked, or deteriorated through long periods of underinvestment, and many more are simply a pole.

This matters for a city grappling with rising congestion, increasing household transport expenditure, and a heavy reliance on private vehicles. In Malaysia, the rise in car ownership can be attributed in part to the expanding urban population and the increase in citizens' disposable income[1]. On the other hand, planning and development decision in Greater KL have, over time produced a dispersed and car-oriented urban form[2], where low densities and functional separation undermine the effectiveness of public transport and quietly entrench private vehicles as the default mode of travel.

The consequence of these is somewhat recognized. Residents living in Greater KL suffer from inefficiencies in the form of congested roads, long commutes and increased financial pressure on households. Public transport plays a crucial role in meaningfully easing these burdens, while supporting the economic productivity of our city[3].

Mass transit systems such as the MRT or LRT provide efficient alternatives to road traffic, helping to shorten travelling times. At typical operating loads, a single MRT train can carry the passenger equivalent of several hundred private cars[4]. Cascajo in their study "Impacts of the Economic Crisis on Household Transport Expenditure and Public Transport Policy: Evidence from the Spanish Case," found that effective transportation policies can help curb private car usage while also easing the financial burden of high living costs on households[5]. In Malaysia, 11.0% of mean monthly household consumption expenditure was spent on transportation, a figure that can be reduced by utilizing public transit[6]. Yet, the challenge remains. Public transport will struggle to attract new riders when the point of entry into the system can at times be uncomfortable, unsafe or unreliable.

Enhancing the quality of public transport services is an effective way to encourage more people to choose public transportation[7]. Among various performance indicators, passenger safety

[1] Ariffin and Zahari (2013)
[2] Hidayati, Yamu, and Tan (2021)
[3] wilkie (2010)
[4] Vuchic (2007); Brinckerhoff (2013)
[5] Cascajo et al. (2018)
[6] "Household Expenditure Survey Report Malaysia 2022" (2023)
[7] Kamba, Rahmat, and Ismail (2007)

remains one of the most critical factors in encouraging greater use of public transport systems[8]. Improving safety standards must include not only the protection of passengers while on board but also ensuring their safety when waiting at or accessing bus stops.

For women in particular, transportation is not just a matter of mobility, but it is deeply tied to personal safety and comfort. Evidence from our Qualitative Interviews[9], as well as the Asian Development Bank, women consistently report higher levels of concern regarding safety[10] and security while using public transport, and they experience two to three times higher levels of fear of crime than men[11]. These anxieties are often intensified by the conditions of the surrounding built form, including poorly designed or inadequately maintained bus stops.

Moreover, pedestrians near bus stops face elevated risks of injury or fatality, with contributing factors including unsafe pedestrian behavior like rushing to catch a bus, the absence of pedestrian infrastructure such as sidewalks, and hazardous road conditions such as high traffic speeds, multiple lanes, and limited visibility[12]. Despite these risks, bus stop infrastructure in many regions remains inconsistent and often neglected in planning processes. In Malaysia, responsibility for bus stop provision is fragmented across agencies and local authorities. There is no consistently enforced national design standard. As a result, bus stops vary widely in quality and amenities, an issue we examine empirically in this study. While some stops offer shelter, seating, and signage, others amount to little more than a pole on the roadside. This inconsistency undermines both the usability and perceived safety of the public transport network.

This research aims to assess this gap by employing machine learning and computer vision techniques to systematically identify and assess bus stops across Greater Kuala Lumpur. By analyzing visual features in large-scale street-level imagery, this study seeks to map the current state of bus stop infrastructure and highlight disparities in design and amenity provision. Our analysis reveals that the quality of bus stop infrastructure is highly variable, often failing below what is needed to support a comfortable and secure waiting environment.

Conceptually, this paper treats bus stops as a critical element of the public transport choice architecture. While service frequency and travel time shape system-level performance, the waiting environment shapes how commuters cognitively experience reliability, safety, and effort. These perceptual effects can deter public transport use even when operational performance is adequate. By systematically assessing bus stop infrastructure, this study evaluates whether the point of entry into the public transport system supports or undermine broader mode-shift objectives.

This paper is structured as follows: Section 2 provides a literature review on the perceived waiting time at the bus stop and the importance of bus stops in shaping commuter experience. Section 3 details the methodology of the computer vision model, including data sources and supervised machine learning techniques. Section 4 presents the findings of the standardized bus

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[8] Jaiswal (2023)
[9] Shukri Mohamed Khairi and Gregory Ho Wai Son (2025)
[10] Asian Development Bank (2023)
[11] Stark and Meschik (2018)
[12] Phillips, Hagen, and Berge (2021)

stop model and the policy recommendations of our findings. Finally, section 5 concludes with the limitations and directions for future research.

2. Literature Review

Bus stops are one of the most important, yet underexamined components of the public transport system. They function as the primary interface between riders and transit services[13]. While the performance of vehicles often receives more attention, a growing body of evidence suggests that conditions at the bus stop influence how commuters perceive waiting, how secure they feel, and whether they ultimately choose public transport over private vehicles.

2.1. Safety, Comfort and the Waiting Environment

Passenger safety is identified to be one of the strongest determinants of transit use[14]. It is noteworthy that research on bus stop safety remains varied within the broader scope of public transport safety, even though bus stops pose high accident risks due to the large volume of passenger movement[15].

In Malaysia, many bus stops lack proper facilities, with most consisting of nothing more than a single pole by the roadside without any shelter, or amenities. Poorly designed bus stops can lead to unsafe behaviours among passengers, bus operators, and pedestrians, increasing the likelihood of accidents[16]. Importantly, travellers' perceptions of safety often outweigh the actual level of safety provided[17].

According to Transit Capacity and Quality of Service Manual, Third Edition[18], the following are some of the questions riders may consider when weigh the comfort and convenience of transit against other competing modes.

- Is the service reliable?
- How long is the wait? Would shelter be available at the stop while waiting?
- Are there any security concerns? During walking, waiting, or riding?
- How comfortable is the trip? Would I have to stand?
- Are the vehicles and transit facilities relatively clean?

Travellers' perception of safety has emerged as one of the key indicators of overall travel satisfaction. Hence, there is a strong need to improve qualification in areas with large passenger volumes to enhance road safety. Sun conducted a study using the Partial Least Squares Structural Equation Model (PLS-SEM) to develop a public transport passenger satisfaction index[19]. The findings revealed that safety, convenience, reliability, comfort, and operational service all have a

[13] Cheranchery et al. (2019)
[14] Kamba, Rahmat, and Ismail (2007)
[15] Phillips, Hagen, and Berge (2021)
[16] Cheranchery et al. (2019)
[17] Abenoza, Cats, and Susilo (2017)
[18] Brinckerhoff (2013)
[19] Sun et al. (2022)

substantial impact on passenger satisfaction. Ensuring safe conditions at bus stops and providing adequate basic amenities are therefore crucial not only to prevent severe accidents but also to encourage greater public transport use.

2.2. Perceived Waiting Time and its Behavioral Effects

Waiting time plays a central role in shaping rider satisfaction. Yet, perceptions of waiting often diverge significantly from actual experienced time. Perceived waiting time is not a fixed construct. It is elastic and shaped by environmental conditions, psychological comfort and also the availability of information.

Fan et al. (2016) demonstrates that passengers waiting at stops without amenities often perceive their waiting time can range from 1.5 to even 4 times longer than actual waiting time, depending on environmental and psychological factors[20]. These effects are substantial, given that they occur without any change in service frequency.

Environmental context and amenities at bus stops significantly affect this perception. Research suggests that certain physical improvements can effectively reduce the perceived burden of waiting. For example, the Multimodal Level of Service Analysis for Urban Streets found that bus shelters with roofs and end panels reduced perceived waiting time by 1.3 minutes, while basic shelter and lighting resulted in reductions of 1.1 and 0.7 minutes, respectively[21]. This effect translates perceived improvements into real user benefits, making waiting feel shorter and more tolerable.

A comprehensive study titled *Perception of Waiting Time at Transit Stops and Stations* by Fan et al. (2016) supports this claim with empirical evidence from the Twin Cities metropolitan area in the United States[22]. The researchers conducted an on-site survey and regression analysis involving over 800 transit users to examine the relationship between stop amenities and perceived waiting time. They found that passengers waiting at stops without any amenities often perceived their waits to be up to twice as long as the actual wait time. Even the presence of a simple bench was associated with significantly lower perceived waiting times, particularly during longer waits. The effect was even more pronounced when a shelter was provided, and combining a bench, a shelter, and real-time information displays brought the perceived wait duration close to the actual measured wait, highlighting the powerful psychological benefits of basic infrastructure.

Moreover, perceived safety of the waiting environment disproportionately affects women. In insecure or poorly lit neighbourhoods, women perceived their wait time as far longer than men did under similar conditions. For example, in insecure environments, a 10-minute wait could feel like 30 minutes to a female passenger, highlighting the psychological stress imposed by poor-quality or unsafe environments. However, the provision of basic amenities at these bus stops can substantially mitigate this disparity, creating a more equitable waiting experience. Conversely,

[20] Fan, Guthrie, and Levinson (2016)
[21] Alessandretti et al. (2023)
[22] Fan, Guthrie, and Levinson (2016)

the absence of cleanliness or maintenance also influenced the perception of waiting time. A bus stop that is dirty or poorly maintained bus stops can make a 5-minute wait feel like 10 minutes or more, demonstrating that negative environmental cues can amplify time distortion due to discomfort or stress.

In summary, bus stop design and amenities play a decisive role in shaping the perceived duration of waiting. Hence, improving bus stop infrastructure should be a strategic priority for transit agencies aiming to enhance the attractiveness of public transportation.

2.3. The Elements of a Quality Bus Stop

A quality bus stop is defined not merely by the presence of a bus sign, but by a set of essential amenities that contribute to safety, comfort, and user-friendly public transit experience. While the definition of quality may vary by urban context, several universally endorsed amenities consistently emerge across international guidelines: the *Berkeley-Charleston-Dorchester Council of Governments (BCDCOG) Transit and Bus Stop Design Guidelines* (2021)[23], the *New Zealand Transport Agency (NZTA) Public Transport Design Guidance*[24] and the *National Association of City Transportation Officials (NACTO) Transit Streets Design Guide*[25] representing North American cities*.* Across all three references, several core elements consistently emerge as critical to ensuring a positive passenger experience.

Shelters are among the most critical amenities, providing physical protection from weather and security	• The *BCDCOG* requires shelters at high-activity and transfer stops, recommending ADA-compliant and durable designs (BCDCOG, 2021, p. 5-18). • Similarly, both *NACTO* and *NZTA* underscore the necessity of shelters in all-weather environments, particularly in regions with high rainfall or extreme sun exposure.
Benches and seating enhance comfort, especially for the elderly, people with disabilities, and passengers with long waits.	• The *BCDCOG* recommends that benches be securely fixed, constructed with heat-tolerant materials, and ideally incorporated into shelters (BCDCOG, 2021, p. 5-16). • The *NZTA* adds that seating should offer back support and a reasonable height for ease of use, reflecting universal design standards.
Lighting is critical for visibility and safety.	• The *BCDCOG* states that adequate lighting should be provided at most stops and can include solar-powered units or integrated shelter lights (BCDCOG, 2021, p. 5-8).

[23] Berkeley-Charleston-Dorchester Council of Governments (BCDCOG) (2021)
[24] "PDF," n.d.
[25] National Association of City Transportation Officials (2016), now North American cities and Transit Agencies (NACTO)

	• Both *NACTO* and *NZTA* emphasize lighting design that avoids shadows and enhances pedestrian visibility.
Bus stop signs are essential for system legibility.	• Clear, well-positioned signage provides route information, stop IDs, and operator branding. According to *BCDCOG*, signage must clearly display route information and be mounted at accessible heights with high-contrast, legible fonts for maximum visibility (BCDCOG, 2021, pp. 5-5 to 5-7). • *NACTO* further encourages the inclusion of route maps, schedules, and real-time information displays to reduce uncertainty and improve user confidence.
Trash bins contribute to cleanliness and the perception of service quality.	• *BCDCOG* guidelines recommend that trash bins should be placed near waiting areas but not obstruct accessibility (BCDCOG, 2021, p. 5-14). • *NZTA* similarly notes that litter-free environments enhance user comfort and reduce operational maintenance costs.
Road markings and curb management are essential for ensuring safe boarding and traffic flow.	• *NACTO* emphasizes the use of clear curb markings and bus stop zones to improve boarding efficiency and avoid double parking, particularly in dense urban areas. • The *NZTA* adds that marked pedestrian crossings near stops support safer passenger movement across streets.

Together, these six elements form the backbone of a functional bus stop. Their absence reduces comfort, increases risk and weakens the perceived reliability of the entire system.

3. Methodology

The study develops a computer vision pipeline to systematically evaluate bus stop infrastructure across Greater KL. The methodology consists of 4 components:

1. Assembling a geolocated bus stop dataset;
2. Collecting Street-level imagery;
3. Preparing annotated training data; and
4. Training a Roboflow Detection Transformer (RF-DETR (Small)) object detection model to identify key bus stop amenities.

3.1. Data Sources

Bus Stop Coordinates

Two primary datasets were used to locate bus stops:

1. GTFS Static Data from Rapid KL
    a. The GTFS feed provides stop IDs, names, and geographic coordinates for Rapid KL Services. This dataset serves as the backbone for identifying formal bus stop locations
2. OpenStreetMap (OSM) API for Smart Selangor Stops
    a. To complement GTFS coverage, additional bus stops used by Smart Selangor services were extracted using the OSM API.

Google Street View Imagery

To capture the infrastructure conditions for each bus stop, we constructed an API-based script to batch download Google Street View imagery for all coordinates. For each bus stop, images were requested from multiple compass headings (typically at 0°, 90°, 180°, and 270°) to minimize occlusion and ensure full visibility of all stop elements and surroundings.

From the initial set of 10,565 street-view images, 2,989 were chosen during filtering. Since each bus-stop coordinate generated four images from different viewing angles, multiple perspectives had to be reviewed to determine which angles contained the bus stop. Figure 1 illustrates an example of the four-directional images for a single bus stop.

Figure 1: Example of the four-directional images for a single bus stop.

3.2. Supervised Learning Approach

This study adopts a supervised object detection approach, where the model learns to identify and recognize specific visual patterns representing the presence or availability of key bus stop infrastructure elements based on manually labelled input data.

By manually annotating a portion of the images, the model learns the relationships between visual features and corresponding labels, allowing it to later detect and classify those elements in unseen images. Supervised learning workflows typically require the dataset to be divided into three subsets:

1. A **training set** for learning;
2. A **validation set** for tuning and monitoring performance during training; and
3. A **test set** for evaluating final model accuracy.

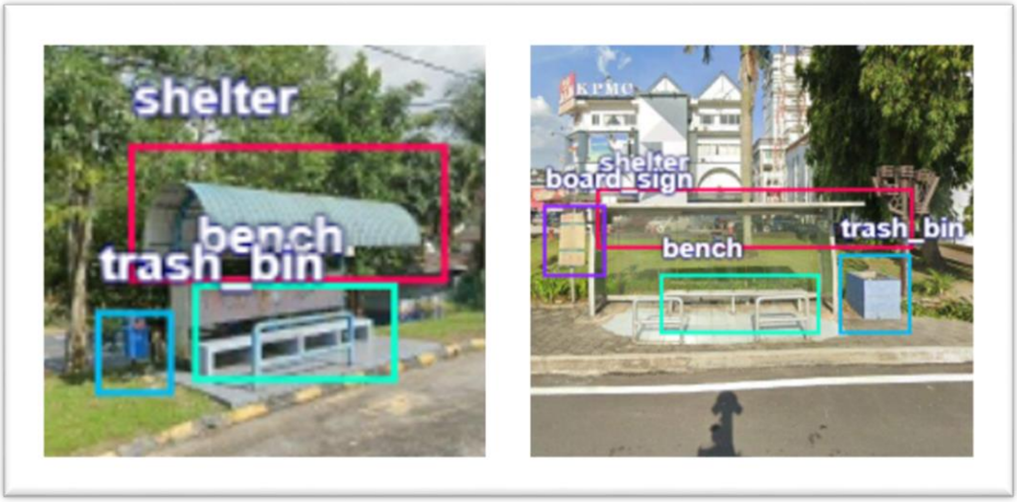
3.3. Image Annotation and Dataset Preparation

Following the data acquisition stage, the dataset was iteratively expanded, with images added progressively to improve coverage of different bus stop types, lighting conditions, and environmental contexts. A preliminary bus stop detection model trained on Roboflow was used with label assist to suggest annotations, which significantly sped up the process.

All images were manually verified and corrected by humans to ensure accurate labels. The annotated objects included key physical amenities based on what our literature review defines a quality bus stop attributes: shelter, bench, bus stop board sign, stop sign, trash bin, streetlight, and bus road markings. On top of that, we added zebra crossings and rumble strips representing road features that contribute to pedestrian safety.

This iterative, model-assisted approach ensured efficient annotation while maintaining high accuracy for downstream object detection and scoring tasks.

Figure 2: Example of annotated images of bus stops.



Preprocessing and Augmentation

To reduce model bias, enhance dataset quality and model generalizability, a series of preprocessing and augmentation techniques were applied through Roboflow's pipeline. These steps were essential to help the model learn effectively from limited annotated data and perform well under varied real-world conditions.

1. **Preprocessing Steps:**
   - **Auto-Oriented**: This step standardized image orientation by removing EXIF rotation metadata, ensuring that all images have a consistent pixel alignment. This reduces confusion during training and helps the model interpret object positions correctly, regardless of how the image was captured.
   - **Resize to Standard Dimensions**: All images were resized to a consistent resolution (e.g., 512×512) as part of Roboflow's preprocessing pipeline. This ensures uniform input size for the model, simplifies batch processing, and helps improve detection performance across images captured under different conditions.

2. **Augmentation Techniques:**
   - **Flip**: Horizontal flips were applied to increase data variability. This helps the model become invariant to changes in viewing direction, which is important for objects like signs or benches that may appear mirrored depending on the camera's position.
   - **Rotation**: Images were rotated randomly between -15° and +15° to simulate small camera angle variations and improve model robustness to slight orientation changes.
   - **Grayscale**: Approximately 15% of images were converted to grayscale to help the model generalize under varying lighting and color conditions.
   - **Blur**: A slight blur of up to 2.5px was applied randomly to simulate motion blur or focus issues, helping the model handle real-world image imperfections.

Figure 3: Preview of pre-processed and after flip, rotation, grayscale, and blur.

These processes expanded the dataset from 2,989 to 5,054 images, significantly improving the diversity and robustness of the training samples while mitigating overfitting risks.

Dataset Splitting

The final dataset was divided into three subsets as follows:

- **82% Training Set**: Used for model learning and parameter optimization.

- **10% Validation Set**: Used to monitor the model's performance during training and prevent overfitting.
- **8% Test Set**: Used as an unseen set to objectively evaluate the model's final accuracy and generalization ability.

Given the modest size of the annotated dataset, and the presence of class imbalance, a slightly larger training set was allocated (82%) to maximize feature exposure while maintaining sufficient validation and test sets for model tuning and unbiased evaluation.

3.4. Model Training using RF-DETR Small

The object detection model used in this study is RF-DETR Small (Roboflow's Roboflow Detection Transformer model), which is optimized for accurate object detection in complex real-world scenes. Training was conducted entirely within the Roboflow platform, leveraging its built-in augmentation, preprocessing, and label assist features.

The iterative training process involved progressively adding images to the dataset and retraining the model to improve detection accuracy for the key elements. Human-verified annotations ensured that the model learned from high-quality data. This architecture is particularly suited to the task at hand, given that objects may be small, partially occluded, or embedded in visually cluttered scenes.

Model Evaluation

During training, the model's performance was monitored on validation data, with metrics such as mAP50, precision, and recall used to evaluate detection quality. The trained RF-DETR Small model was then used to assist with further annotations and to generate predictions for downstream scoring and visualization tasks.

Table 1: The test evaluation of the latest trained model

Class name	True Positive	False Positive	False Negative	mAP50	precision	recall
Bus road marking	63	7	30	0.760	0.900	0.677
Bench	166	32	52	0.830	0.838	0.761
Board sign	39	11	22	0.770	0.780	0.639
Bus	18	1	5	0.960	0.947	0.783
Rumble strips	34	11	22	0.740	0.756	0.607
Shelter	209	15	26	0.940	0.933	0.889
Stop sign	27	12	33	0.480	0.692	0.450
Streetlight	145	53	76	0.750	0.732	0.656
Trash bin	48	10	20	0.780	0.828	0.706
Zebra crossing	5	1	7	0.430	0.833	0.417
ALL	754	153	293	0.744	0.824	0.659

As shown, the trained model achieved the following overall metrics across 123 validation images:

- Mean Average Precision (mAP@0.5): 0.744
- Precision (P): 0.821
- Recall (R): 0.654

Among the individual elements, the model performed particularly well in detecting benches (mAP@0.5 = 0.830), shelters(0.940), and trash bins (0.780), while performance on elements with fewer training instances (e.g., zebra crossings, stop signs) was more limited.

Annotated outputs with the help of the RF-DETR model were downloaded in a YOLOv8 format, which outputs bounding box coordinates and associated confidence scores into structured text files, which were parsed and processed for analysis.

Quality Scoring and Classification

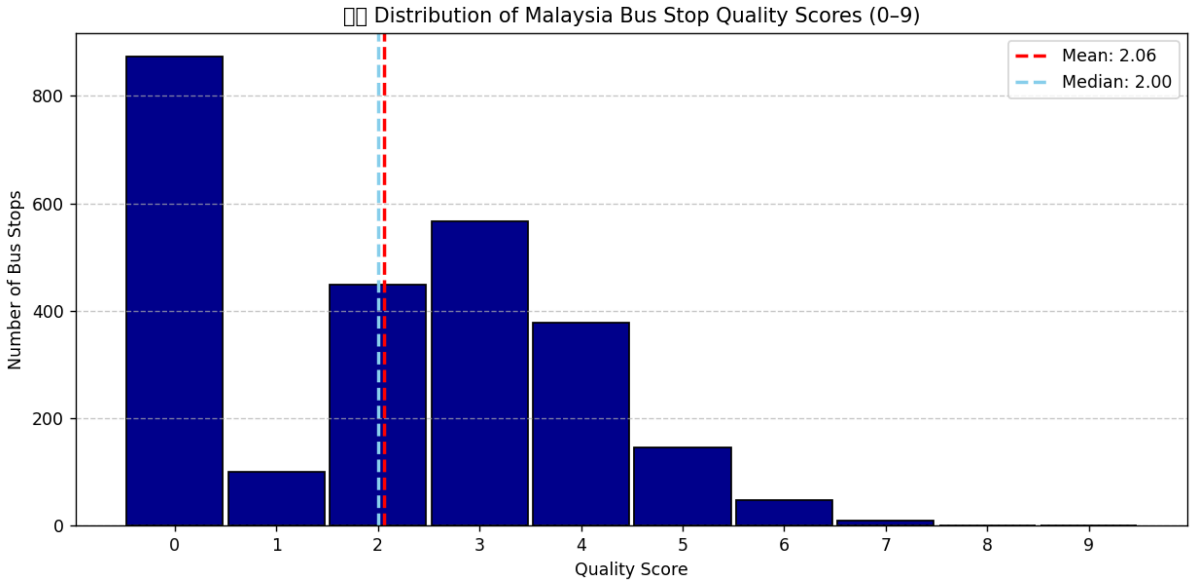
Based on the model's output, each stop was evaluated based on the presence of nine key elements: shelter, bench, bus stop board sign, stop sign, zebra crossing, rumble strips, streetlight, trash bin, and bus road markings. Each detected element contributed equally to the total score, yielding a maximum possible quality score of 9 points.

When all four core elements – bus road markings, a board sign, a shelter and a stop sign are absent, the stop is assigned a quality score of zero. This configuration represents locations where no formal visual or physical cues indicate the presence of a bus stop. In such cases, the service is effectively invisible to unfamiliar users.

Given the absence of locally validated preference weights for bus stop amenities in Malaysia, this study adopts an equal-weight scoring scheme as a conservative baseline. The objective is not to estimate utility trade-offs, but to identify minimum structure adequacy and systematic gaps across the bus network.

The scoring revealed a generally low standard of infrastructure across the network, with Rapid KL bus stops averaging only 2.06 out of 9. The following is the ditribution of scores across all the bus stops:

Figure 4: Bar Chart of Distribution of Malaysia Bus Stop Quality Scores



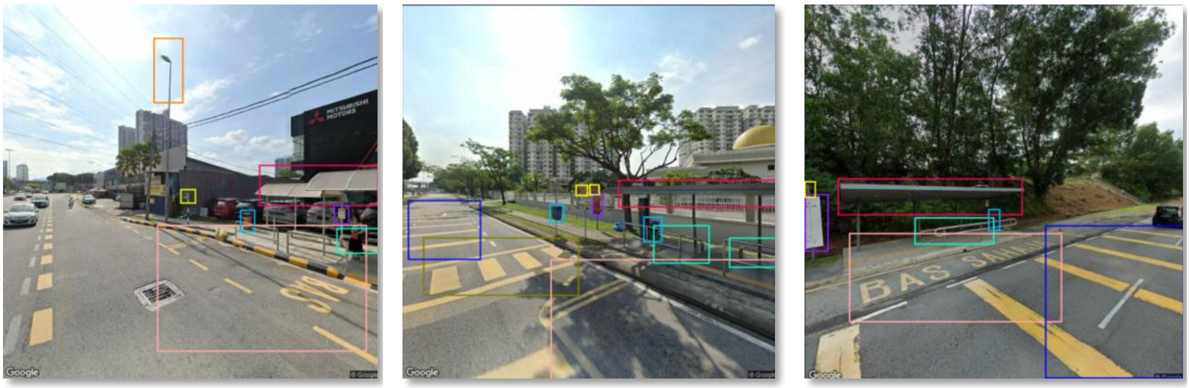
Below are the score ranges with their corresponding sample images for reference:

Score of 0:

Score range of 1 – 3:

Score range of 4 – 6:

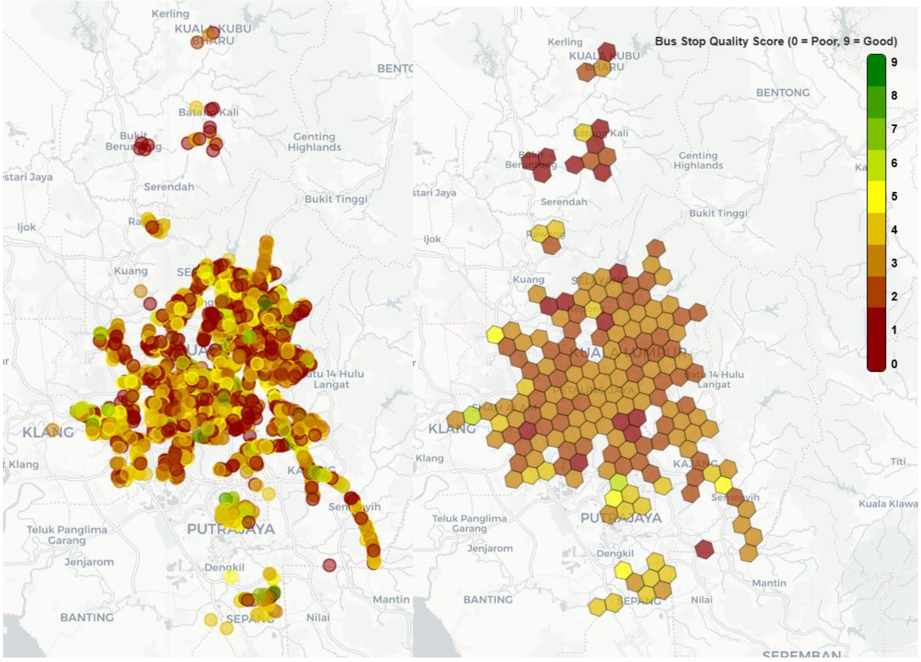
Score range of 7 – 9:



3.5. Interactive Mapping and Visualization

To spatially interpret the quality scores of bus stops across Selangor, an interactive web-based map was developed using the Folium Python package. Folium leverages the Leaflet.js library to enable interactive geospatial visualizations directly from Python, allowing for intuitive exploration of geographic data.

Figure 5: Preview of the interactive bus stop quality map developed using Folium.



Each bus stop was plotted on the map using its geographic coordinates (latitude and longitude) sourced from both the GTFS dataset and Open Street Map dataset. A circle marker was assigned to every stop, with visual encoding based on the bus stop's computed quality score:

- Colour Gradient: A continuous colour scale from dark red to dark green was applied, where:
  - Dark Red (score near 0) indicates poor-quality stops
  - Dark green (score near 9) indicates high-quality stops.

This visualization enables users to quickly identify spatial patterns in bus stop quality, highlighting underserved areas, high-performing clusters, and opportunities for targeted infrastructure improvement. For some added perspective, the median quality score is 2.00, and only 58 bus stops scored above 6, as shown in the bar chart in Figure 5. The final map was exported as an HTML file for easy sharing and integration into reports or web platforms.

Additionally, Moran's Index and its associated statistics, including the z-score and p-value, were calculated to assess spatial autocorrelation further. The results are summarised below:

Table 2: Moran's Index calculation results.

Moran's I	Expected I under randomness	p-value (permutations)	z-score (permutations)
0.10398067825170319	-0.000390015600624025	0.001	11.286819741508074

Moran's I value of 0.104 indicates a weak but positive spatial autocorrelation in bus stop quality scores, meaning nearby bus stops tend to have slightly similar quality levels rather than being randomly distributed. Although the magnitude of clustering is small, it still suggests that local neighbourhood effects exist, where areas with higher-quality stops tend to be near one another, and the same is true for lower-quality areas. This pattern is consistent with neighbourhood-level planning, development age and jurisdictional differences in infrastructure provision.

This pattern is statistically significant, as shown by the very small p-value (0.001) and the high z-score (11.29). These values indicate that the observed clustering is extremely unlikely to have occurred by chance. In other words, the spatial pattern in bus stop quality is real, not random, and reflects meaningful geographic structure across the study area.

3.6. Limitations

There are limitations. Firstly, the methodology relies heavily on Google Street View (GSV) as the sole source of image data. Although GSV offers widespread spatial coverage and convenience, its passive nature introduces inherent constraints. The timing and angle of image capture are not controlled by the researcher. Passing vehicles, vegetation, or construction barriers will somehow block parts of the bus stop from view. In some instances, essential elements like benches, signage, or trash bins may be entirely hidden, leading to under-detection by the model and potentially misrepresenting the actual quality of the stop.

Secondly, the images were captured at different dates and years, so some data may not accurately reflect current on-site conditions, further affecting the reliability of the assessment.

Thirdly, the dataset used for training the object detection model exhibited class imbalance. Certain bus stop elements (e.g., shelters and benches) were more commonly present and thus more frequently annotated, while others like trash bins, road markings, or streetlights appeared less frequently in the training set. This imbalance can bias the model's learning, resulting in lower detection accuracy for underrepresented classes. To mitigate this, data pre-processing and augmentation techniques were applied to artificially increase the diversity and representation of rare classes. While these steps help address the issue to some extent, they cannot fully replicate real-world variability, so stops that possess these less-visible elements may still not receive a quality score that truly reflects their infrastructure..

Fourthly, the definition of bus stop quality in this study, while grounded in international guidelines, was operationalized using only nine visual elements. This approach omits other critical factors influencing perceived quality and usability, such as safety from crime, pedestrian connectivity, real-time information systems, or the presence of nearby shelters like shops or malls. Therefore, while the model captures physical attributes well, it may not fully reflect the lived experience of transit users, especially in diverse urban environments.

Additionally, while the object detection model performed reasonably well overall, the evaluation relied on standard metrics (mAP, precision, recall) and limited validation images. There may be domain-specific misclassifications that are contextually relevant in Malaysia but not adequately represented in the training data. Furthermore, the use of 90-degree rotation and flip augmentation may not fully replicate the variability encountered in real-world deployments, such as heavy shadowing or nighttime lighting conditions.

4. Discussion of Findings

4.1. Widespread Absence of Essential Amenities

The results of this study underscore the generally poor condition of bus stop infrastructure in Selangor, with the average quality score of Rapid KL bus stops reaching only **2.06 out of 9**. The low average quality score reflects a system where essential components of the waiting environment are either missing or inconsistently provided. These deficiencies negatively impact all commuters, but they disproportionately burden groups with greater sensitivity to safety and comfort, such as women, the elderly and persons with disabilities.

The model reveals that **shelters**, **benches**, **lighting**, and **trash bins** are among the most frequently missing elements. Their absence exposes commuters to heat and rain, reduces comfort for those who cannot stand for long periods, and erodes perceptions of system reliability. Poor illumination affects safety, limits visibility of approaching busses and discourages evening travel, particularly among women.

4.2. Spatial Patterns from Hexagonal Aggregation

The hexagonal-level aggregation reveals clear structural patterns in bus stop quality across Greater KL. A large, contiguous belt of low-quality stops covers the KL and Petaling Jaya core, extending north-south along major travel corridors. This area contains some of the highest residential densities in the region, yet they are consistently scored poorly, suggesting that infrastructure provision has not kept pace with what could be operational demand.

Peripheral municipalities show more variation. Areas such as Putrajaya, Cyberjaya, and parts of Sepang show pockets of moderate-good quality stops, reflecting newer development patterns and more recent infrastructure investment. Notably, the map shows almost no high-quality clusters in Greater KL. The absence of consistently well-equipped zones underscores a systemic gap in design standards. These spatial patterns reinforce the need for a coordinated, region-wide strategy to upgrade bus stop infrastructure.

4.3. Policy Recommendations

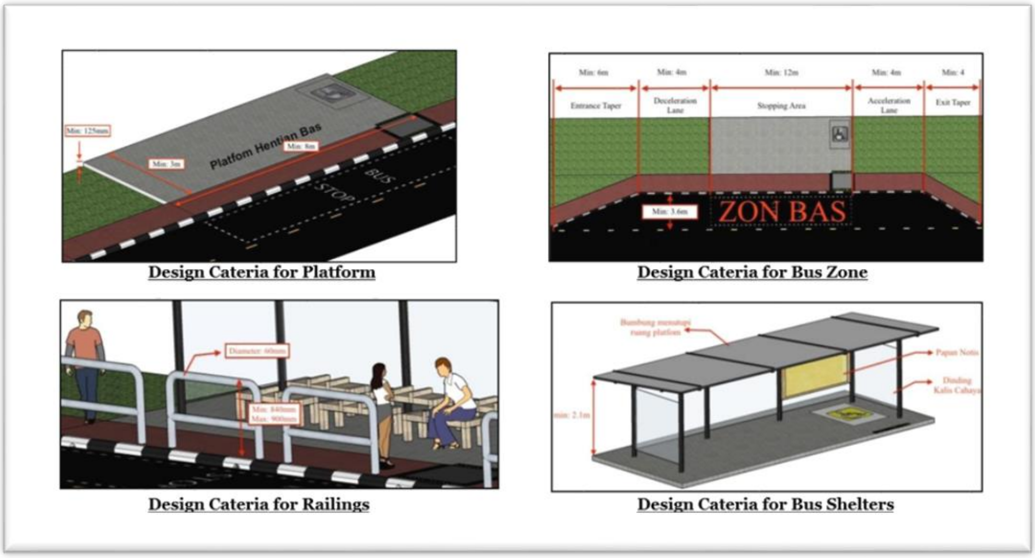
The pattern observed in Greater KL indicates persistent amenity gaps, inconsistent design, municipal disparities, and the absence of high-quality clusters. Addressing these deficiencies requires a coordinated approach supported by clear infrastructure standards and tools that directly improve the waiting experience of a commuter. The evidence also shows that several improvements are both operationally feasible and cost-effective. This sets the stage for two policy measures that respond to the structural problems identified.

1. Adopt a National Standard Bus Stop Design Framework

Our analysis reveals that bus stop quality varies widely across municipalities, with most failing to provide even basic amenities such as shelters, benches, or lighting. The absence of a shared design framework has resulted in inconsistent implementation, uneven maintenance, and limited accountability. A national standard would provide a uniform baseline that ensures minimum levels of safety, accessibility, and comfort regardless of jurisdiction.

The Universiti Sains Malaysia (USM) campus study[26] offers a practical foundation, its framework incorporates universal design principles and meet the needs of diverse users. The USM guideline recommends 13 core components, including shelter, seating, lighting, waste bins, accessible boarding areas, real-time information, and safe pedestrian access. Adopting a similar model at the national scale would help local governments plan, prioritize and upgrade their infrastructure systematically.

Figure 6: Proposed design of bus stop by USM campus case study.



A tiered system (basic, standard, premium) would allow municipalities to match investment levels to context while ensuring that all stops meet core accessibility and safety requirements. Implementation should prioritize high-ridership corridors, and stops that serve major employment, education and healthcare facilities.

2. Deploy Real-Time Arrival Information Systems

The integration of real-time transit information, delivered through LED displays, call or text-based services, or mobile apps has been proven to reduce passenger uncertainty and improve perceptions of service reliability. Multiple international studies have documented the psychological and behavioural benefits of such systems:

- In Seattle, real-time app users reported **30% shorter perceived wait times** compared to non-users[27].
- A study in The Hague showed that countdown displays at tram stops reduced perceived wait time by **20% (1.3 minutes)**[28].

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[26] Bidin, Mutti, and Mohd Yassin (2018)
[27] Watkins et al. (2011)
[28] Dziekan and Kottenhoff (2007)

- In London, real-time arrival information at Underground stations reduced wait time overestimation by **0.7 minutes**, while **89%** of surveyed passengers agreed that the waiting experience was more acceptable with the information[29].
- After deploying countdown displays at bus stops, **65%** of London bus users felt they waited less time, and **83%** reported that time passed more quickly, despite bus frequency remaining unchanged[30].

These findings demonstrate that perception of wait times, not just service frequency, shapes user satisfaction. As such, even in areas where increasing bus frequency may not be feasible due to budget constraints or other limitations, providing real-time information can meaningfully improve rider experience while waiting.

Greater KL already possesses the technological foundation for implementation, given the availability of the GTFS real-time feeds. Deploying real-time information through countdown displays would offer substantial improvements at relatively modest cost. This measure is especially valuable in contexts where frequency is low and increases in bus frequency is not immediately feasible.

5. Conclusion

This study demonstrates the value of using computer vision to systematically assess bus stop infrastructure across Greater KL. By combining geospatial data, Google Street View imagery, and a transformer-based object detection model, we provide a scalable method for evaluating amenities that shape various aspects of safety, comfort, and accessibility of public transport. The results reveal substantial and systemic gaps.

Together with companion studies on bus reliability and commuter experience under the Greater KL Mobilities project[31], these findings highlight how operational performance and physical waiting environment jointly shape public transport viability. Many stops lack shelters, benches, lighting, or clear signage. Few locations achieve high-quality standards. The absence of consistently well-equipped stops points to structural issues in design and planning. These findings matter because the waiting environment directly influences perceived waiting time, safety and the decision to use public transport. A system that aspires to shift travel behavior cannot overlook the experience of commuters at the point of first contact. Improving bus stops is therefore not a peripheral task. It is a central component of building a more reliable and equitable transport network.

Two policy directions emerge from the evidence. A national bus stop design standard would provide municipalities with a uniform baseline for planning, upgrading and maintaining infrastructure. Real-time information systems would enhance predictability and reduce the psychological burden of waiting. Together, these measures address both the physical and

[29] Lu et al. (2018)
[30] Transport for London (2023)
[31] Shukri Mohamed Khairi and Gregory Ho Wai Son (2025); Kelvin Ling Shyan Seng and Gregory Ho Wai Son (2025)

perceptual dimensions of the waiting experience and can be implemented with relatively modest investment.

6. References

Abenoza, Roberto F., Oded Cats, and Yusak O. Susilo. 2017. "Travel Satisfaction with Public Transport: Determinants, User Classes, Regional Disparities and Their Evolution." *Transportation Research Part A: Policy and Practice* 95 (January):64–84. https://doi.org/10.1016/j.tra.2016.11.011.

Alessandretti, Laura, Luis Guillermo Natera Orozco, Meead Saberi, Michael Szell, and Federico Battiston. 2023. "Multimodal Urban Mobility and Multilayer Transport Networks." *Environment and Planning B: Urban Analytics and City Science* 50 (8):2038–70. https://doi.org/10.1177/23998083221108190.

Ariffin, Raja Noriza Raja, and Rustam Khairi Zahari. 2013. "Towards a Sustainable Urban Transport System in the Klang Valley, Malaysia: The Key Challenges." *Procedia - Social and Behavioral Sciences* 85 (September):638–45. https://doi.org/10.1016/j.sbspro.2013.08.391.

Asian Development Bank. 2023. "Enhancing Gender Equality in Infrastructure Development: Theories of Change, Indicators, and Sector Strategies." 0 ed. Manila, Philippines: Asian Development Bank. https://doi.org/10.22617/TCS230608-2.

Berkeley-Charleston-Dorchester Council of Governments (BCDCOG). 2021. "Transit and Bus Stop Design Guidelines." Design Guidelines. Charleston, SC. BCDCOG Planning Department. 19. https://bcdcog.com/bus_stop_design_guidelines/.

Bidin, Mohamad Omar, Mohd Alif Ikrami Mutti, and Hafeezur Rahmaan Mohd Yassin. 2018. "Development of a Bus Stop Design Guideline: Case Study on the Main Campus of Universiti Sains Malaysia (USM)." In *Proceedings of the 4th Bandung Creative Movement International Conference on Creative Industries 2017 (4th BCM 2017)*. Bandung, Indonesia: Atlantis Press. https://doi.org/10.2991/bcm-17.2018.62.

Brinckerhoff, Parsons. 2013. *Transit Capacity and Quality of Service Manual, Third Edition*. Washington, D.C.: Transportation Research Board. https://doi.org/10.17226/24766.

Cascajo, Rocío, Lourdes Diaz Olvera, Andrés Monzon, Didier Plat, and Jean-Baptiste Ray. 2018. "Impacts of the Economic Crisis on Household Transport Expenditure and Public Transport Policy: Evidence from the Spanish Case." *Transport Policy* 65 (July):40–50. https://doi.org/10.1016/j.tranpol.2017.06.001.

Cheranchery, Munavar Fairooz, Kinjal Bhattacharyya, Muhammed Salih, and Bhargab Maitra. 2019. "A Proactive Approach to Assess Safety Level of Urban Bus Stops." *International Journal of Injury Control and Safety Promotion* 26 (3):260–70. https://doi.org/10.1080/17457300.2019.1626442.

Dziekan, Katrin, and Karl Kottenhoff. 2007. "Dynamic At-Stop Real-Time Information Displays for Public Transport: Effects on Customers." *Transportation Research Part A: Policy and Practice* 41 (6):489–501. https://doi.org/10.1016/j.tra.2006.11.006.

Fan, Yingling, Andrew Guthrie, and David Levinson. 2016. "Perception of Waiting Time at Transit Stops and Stations." Research Report / Technical Report CTS 16-01 / TIRP Report #9. Transitway Impacts Research Program. Minneapolis, Minnesota: Center for Transportation Studies, University of Minnesota. Https://www.cts.umn.edu/publications/research-reports/reportdetail/2906. University of Minnesota Digital Conservancy / Center for Transportation Studies. https://www.sciencedirect.com/science/article/abs/pii/S0965856416303494.

Hidayati, Isti, Claudia Yamu, and Wendy Tan. 2021. "You Have to Drive: Impacts of Planning Policies on Urban Form and Mobility Behavior in Kuala Lumpur, Malaysia." *Journal of Urban Management* 10 (1):69–83. https://doi.org/10.1016/j.jum.2020.12.004.

"Household Expenditure Survey Report Malaysia 2022." 2023. Government Report ISSN 1394-3952. Household Expenditure Survey. Putrajaya, Malaysia: Department of Statistics, Malaysia (Jabatan Perangkaan Malaysia). Https://www.dosm.gov.my. Department of

Statistics Malaysia Archive. https://storage.googleapis.com/dosm-public-publications/multiyear_2022_hies.pdf.
Jaiswal, Anuj. 2023. “Assessment of Satisfaction Level for Existing Public Transport Systems Using Machine Learning: A Case of Bhopal (India).” *European Transport/Trasporti Europei*, no. 93 (June):1–18. https://doi.org/10.48295/ET.2023.93.10.
Kamba, Abdalla Nurdeen, Riza Atiq O.K. Rahmat, and Amiruddin Ismail. 2007. “Why Do People Use Their Cars: A Case Study In Malaysia.” *Journal of Social Sciences* 3 (3):117–22. https://doi.org/10.3844/jssp.2007.117.122.
Kelvin Ling Shyan Seng and Gregory Ho Wai Son. 2025. “Assessing Bus Performance in Greater Kuala Lumpur.” Kuala Lumpur: Khazanah Research Institute.
Lu, Hui, Peter Burge, Chris Heywood, Rob Sheldon, Peter Lee, Kate Barber, and Alex Phillips. 2018. “The Impact of Real-Time Information on Passengers’ Value of Bus Waiting Time.” *Transportation Research Procedia* 31:18–34. https://doi.org/10.1016/j.trpro.2018.09.043.
National Association of City Transportation Officials, ed. 2016. *Transit Street Design Guide*. Washington: Island Press.
“PDF.” n.d.
Phillips, Ross O., Oddrun Helen Hagen, and Siri Hegna Berge. 2021. “Bus Stop Design and Traffic Safety: An Explorative Analysis.” *Accident Analysis & Prevention* 153 (April):105917. https://doi.org/10.1016/j.aap.2020.105917.
Shukri Mohamed Khairi and Gregory Ho Wai Son. 2025. “Greater Kuala Lumpur’s Public Transportation and Its Viability: A Qualitative Study.” Kuala Lumpur: Khazanah Research Institute.
Stark, Juliane, and Michael Meschik. 2018. “Women’s Everyday Mobility: Frightening Situations and Their Impacts on Travel Behaviour.” *Transportation Research Part F: Traffic Psychology and Behaviour* 54 (April):311–23. https://doi.org/10.1016/j.trf.2018.02.017.
Sun, Shijie, Ru Chen, Siyuan Qin, and Lufan Liu. 2022. “Evaluating the Public Participation Processes in Community Regeneration Using the EPST Model: A Case Study in Nanjing, China.” *Land* 11 (9):1405. https://doi.org/10.3390/land11091405.
Transport for London. 2023. “New Real-Time Information Signs and Technology to Make Bus Travel Easier in London.” Transport for London. https://tfl.gov.uk/info-for/media/press-releases/2023/march/new-real-time-information-signs-and-technology-to-make-bus-travel-easier-in-london.
Vuchic, Vukan R. 2007. *Urban Transit Systems and Technology*. John Wiley & Sons. https://books.google.com/books?hl=en&lr=&id=zFby0C3ohwQC&oi=fnd&pg=PP1&dq=urban+transit+systems+and+technology&ots=iSaHvu-N8J&sig=68sNz37wv_VzxoS7q4-kv_IQkSU.
Watkins, Kari Edison, Brian Ferris, Alan Borning, G. Scott Rutherford, and David Layton. 2011. “Where Is My Bus? Impact of Mobile Real-Time Information on the Perceived and Actual Wait Time of Transit Riders.” *Transportation Research Part A: Policy and Practice* 45 (8):839–48. https://doi.org/10.1016/j.tra.2011.06.010.
wilkie, caroline. 2010. “The Benefit of Public Transport.” *Tourism & Transport Forum(TTF) Australia*. https://www.scribd.com/document/425576798/Nothingisspecialheteidiot.