Jurnal Kejuruteraan 38(4) 2026: 1949-1956
https://doi.org/10.17576/jkukm-2026-38(4)-30

Integration of Analytical Hierarchical Process (AHP) and GIS in Measuring Level of Services of Rail-Transit System

Nur Aniqah Rushda Mohd Azlisham[a] & Nabilah Naharudin[a,b*]

[a]*Faculty of Built Environment, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA*

[b]*Geospatial Intelligence (Geo-AI), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA*

[*]*Corresponding author: nabilahnaharudin1290@uitm.edu.my*

Received 24 October 2025, Received in revised form 18 April 2026
Accepted 18 May 2026, Available online 30 July 2026

ABSTRACT

Malaysia is currently experiencing rapid urbanisation that led to a more efficient and equitable public transportation systems. Though Light Rail Transit (LRT) systems in Kuala Lumpur did play a key role for urban mobility, spatial variations of Level of Services (LOS) across stations remain insufficiently understood. Hence, this study developed spatial framework that integrated Analytical Hierarchical Process (AHP) and GIS for measuring LOS of rail-transit stations by using four main criteria; accessibility, land use, population and services' quality as the basis. The criteria were weighted using experts' judgement and GIS index modelling was used to derive a composite index map that classify the LOS across the study area. Then, spatial statistical analysis including Average Nearest Neighbor, Global Moran I and Getis-Ord Gi were used to examine the clustering patterns of the LOS. Results revealed a pronounced spatial variation of the LOS where high LOS are concentrated in central urban area. AHP revealed that accessibility is the most dominant factor with 0.571 of weightage indicating the need of considering both operational efficiency and accessibility in measuring LOS. Significant spatial autocorrelation with Moran I of 0.438 shows that the LOS distribution is structurally embedded within the urban form rather that it is randomly distributed. Findings suggested that the disparities in the LOS are driven more by landuse integration and connectivity in addition to the rail-line characteristics. This study provides a replicable GIS-MCDA framework for a spatially-explicit LOS assessment for rail-transit services. It highlights the importance of addressing accessibility gaps to achieve a more sustainable Transit Oriented Development (TOD).*

Keywords: ahp; gis; mcda; Level of Service; accessibility; rail transit

INTRODUCTION

Rapid urbanisation in Malaysia has significantly increased the demand for efficient and equitable public transportation systems, particularly within the Klang Valley. Rail-based systems, especially the Light Rail Transit (LRT), play a critical role in reducing congestion, promoting sustainable mobility, and supporting Transit Oriented Development (TOD) (Wan et al. 2023). Despite substantial investments, inconsistencies in service quality across stations remain a major concern, affecting both system performance and user experience.

The Level of Service (LOS) framework is widely used to evaluate transportation performance through multidimensional indicators such as accessibility, capacity, reliability, and user experience (Bakar et al. 2022). LOS assessments tend to emphasise operational metrics while underrepresenting spatial and socio-economic dimensions. This limitation reduces the ability to capture how urban structure and land influence transit performance.

Recent studies have incorporated Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) to enhance LOS evaluation by integrating spatial variables and human judgment. Although there seems to be significant investments for the development of extensive LRT network in Kuala Lumpur (KL), comprehensive evaluation of the LOS of the system remains limited. Previous studies often focus on how LOS influenced by spatial coverage, multimodal connectivity, and spatial accessibility as well as surrounding landuses on overall service performance (Ibrahim et al. 2023; Naharudin et al. 2020). Some also focuses on services quality (Ibrahim et al. 2022). Consequently, they might be challenges in identifying service disparities and prioritising targeted improvements to support sustainable urban mobility.

To address the gap, this study integrates MCDA and GIS analysis to evaluate the LOS for the LRT system in KL. The study combines expert-driven weighting using Analytical Hierarchical process (AHP) with GIS index modelling to derive spatial LOS model. The framework includes multiple criteria such as accessibility, land use, service quality and socio-economic factors to ensure a more holistic assessment of the LOS. Integration of experts' choice with spatial modelling will aid in identifying areas with high and low LOS.

REVIEW OF LITERATURE

Rail transit systems are fundamental to sustainable urban mobility, particularly in high-density metropolitan regions. In Malaysia, LRT, MRT, and monorail systems serve as critical components of the public transport network, supporting daily commuting and reducing dependence on private vehicles. However, as mentioned earlier, the efficiency of the systems depends on both operational efficiency and spatial integration with surrounding urban environments.

LEVEL OF SERVICE OF RAIL-TRANSIT STATION

LOS framework has traditionally been used to evaluate transport performance based on operational indicators such as frequency, capacity, and travel time. While useful, these metrics often overlook spatial dimensions such as accessibility, land use distribution, and connectivity. This has led to growing interest in integrating GIS-based approaches into LOS evaluation, enabling more comprehensive spatial analysis of service coverage and accessibility.

Accessibility is one of the most significant characteristics, since it reflects how easily people may access train services. It considers station density, distance from the nearest station, connectivity with other forms of transportation, and accessibility to various landuses to support different walking purposes (Naharudin et al. 2020). In addition, ensuring accessibility goes beyond key urban areas to suburban and rural zones, which are frequently underserved, highlights the need for more inclusive planning (Ibrahim et al. 2023).

Service quality is another key aspect in ensuring a good LOS (Ibrahim et al. 2022). Service frequency has direct impact on both customer happiness and operational efficiency (Biswas et al. 2023). High-frequency services minimize passenger wait times, which improves the overall experience and encourages more people to use public transit. The station capacity is another key aspect in measuring services quality that influence LOS (Wang et al. 2023).

Safety and security are another important criterion for establishing public trust and guaranteeing the continuous usage of rail services (Salter & Alexander, 2022; Pawar et al. 2025). Although a good planning could provide good access to the rail-transit services, commuters willingness to walk to the station could be influenced by their perceived safety during the journey (Kåresdotter et al. 2022).

INTEGRATION OF MCDA AND GIS FOR MEASURING LEVEL OF SERVICES OF RAIL-TRANSIT STATION

MCDA, particularly AHP has been widely applied to transportation planning due to its ability to structure complex decision problems and incorporate expert judgement (Malczewski & Rinner 2015; Saaty 1980). The integration of GIS and AHP allows for spatially weighted evaluation of multiple criteria, making it suitable for assessing transit service performance across heterogeneous urban environments.

GIS-based studies have been widely utilized to evaluate the LOS in rail transportation systems, with a primary focus on spatial and operational metrics. For example, buffer analysis is frequently used to define service areas and assess accessibility by mapping how the catchment area of transit stops (Alamri et al. 2023). Walkability and first-mile/last-mile connectivity to transport stations have also been investigated using GIS, highlighting the importance of pedestrian accessibility. Furthermore, overlay analysis is utilized to identify overlapping service regions, hence improving network coverage and efficiency (Alamri et al. 2023). Another prominent use is travelling time modelling, to map the accessibility of mixed landuses around rail-transit services (Bhellar et al. 2023).

Perception-based studies had also widely used to measure the LOS. Commuters' perception on the rail-transit services could be obtained via questionnaire to understand the LOS of a station (Pawar et al. 2025; Romero et al. 2023). Another method that is used for LOS determination is by using inventory of the pedestrian facilities existed at a station (Tola, 2023). While these techniques offer valuable geographical and operational insights, they frequently ignore qualitative features and stakeholder demands. Integrating GIS with MCDA can close this gap by weighting several aspects such as accessibility, environmental implications, and user satisfaction, resulting in more thorough and decision-making.

Integrating GIS with MCDA, especially the AHP might be an effective way for enhancing LOS. AHP helps decision-makers prioritize multiple factors, such as accessibility, efficiency, and service dependability, using a structured pairwise comparison technique. Once these priorities have been identified, GIS can spatially map these elements across the transit network, providing a clear picture of where improvements are required. AHP could enable the systematic evaluation of criteria such as commuter demand and operational efficiency, whilst GIS gave a geographical depiction of these characteristics, identifying locations with major service deficits. This combination enabled planners to focus on underdeveloped areas where extra services or infrastructure may be required.

The primary advantage of integrating AHP and GIS in transit planning is its capacity to systematically include subjective assessments and relate them to real, geographical data (Malczweski & Rinner, 2015). AHP guarantees that stakeholders' critical criteria are prioritized, whereas GIS visualizes these preferences in a real-world environment, enabling for focused actions. This combination not only improves decision-making accuracy, but it also assures that changes are made in the most critical areas.

Hence, this study extends existing literature by embedding spatial statistical analysis within a GIS-MCDA framework and by explicitly interpreting LOS as a manifestation of the sustainability of the services. By doing so, it provides a more nuanced understanding of how accessibility and land use shape transit performance.

METHODOLOGY

This study adopts an integrated GIS-AHP framework that consists of five stages: criteria identification, data collection, AHP weighting, GIS-based analysis, and spatial statistical evaluation.

CRITERIA SELECTION

Four primary criteria were selected based on literature review and expert consultation: accessibility, land use, service quality, and population. Each criterion was further divided into relevant sub-criteria, including connectivity, amenities, commercial density, and population distribution. These criteria were chosen due to their significant influence on LOS. Land use includes institution, health services, and industrial and commercial areas. For accessibility, factors like accessibility to park and ride and connectivity to other modes were considered. In addition, for service quality factor such as accessibility for person with disabilities, retail and services facilities, basic amenities and comfort features were included. The last criteria are the population of the zone or district.

AHP WEIGHTING

AHP was used to determine the relative importance of each criterion through pairwise comparisons conducted by five domain experts (Table 1) using the Saaty scale. The weights were aggregated to derive final criterion importance. While the number of experts is limited, similar studies have demonstrated that small, specialised panels can provide reliable judgement when expertise is domain-specific (Saaty 1980). The consistency of the judgments was verified using the Consistency Ratio ($CR \leq 0.10$), and the final weights were obtained using the geometric mean method.

TABLE 1. List of Experts

Position	Experience (Years)
Research Officer	19
Academician	30
Academician	17
Academician	25
Academician	7

A clear hierarchical structure that incorporates the LOS assessment's criteria and sub-criteria was constructed as shown in Figure 2. This structure usually begins with the goal of the pairwise comparison which is the LOS of rail-transit at the top. The second level cluster consists of main criteria such as the nodes. The third level is the clusters consisting of the sub-criteria under each main criteria for each cluster.

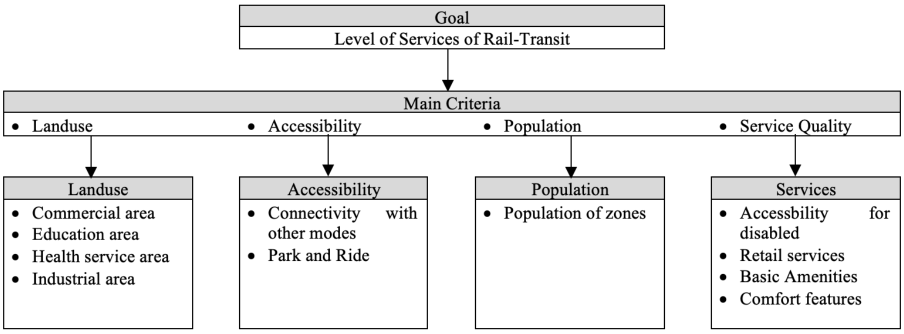


FIGURE 2. AHP Hierarchical Structure

After the hierarchical structure is established, Experts' Choice Form is created comprising pairwise comparison in which experts ranked the significance of each criterion and sub-criterion. The rating obtained then organized into a matrix with C= $[c_{kp}]_{nxn}$, where c_{kp} is the rating during pairwise comparison for the criteria k and p. C is reciprocal matrix where c_kp=c_{kp}^{-1} and all diagonal elements are unity where, c_{kp}=1,, for $k = p$. As it is reciprocal, only $n(n-1)/2$ actual pairwise comparisons are needed in the (n x n) matrix. Once the matrix is made, the weights can be calculated using Equation 1.

$$C_w = \lambda_{max} w \quad (1)$$

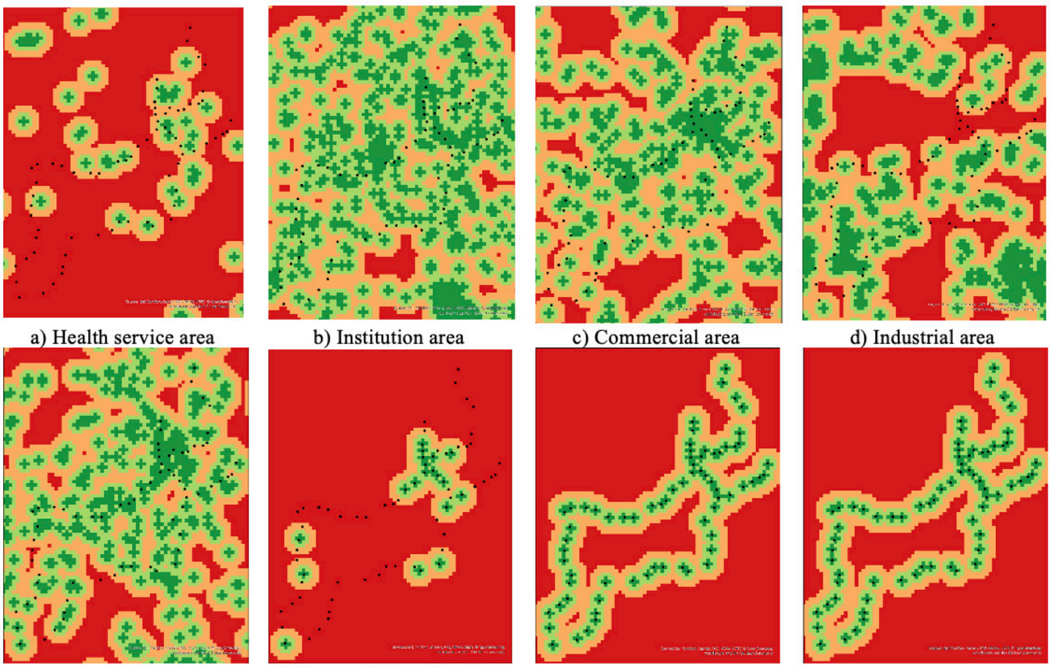
where λ_{max} is the largest eigenvalue of $\boldsymbol{C}$. The criterion weights can be approximated by using a procedure of averaging over normalized columns using Equation 2 and normalized weights for the criteria are then computed using Equation 3.

$$c^*_{kp} = \frac{c_{kp}}{\sum_{k=1}^{n} c_{kp}}, \text{ for all } k = 1, 2, \ldots, n \quad (2)$$

$$w_k = \frac{\sum_{p=1}^{n} c^*_{kp}}{n}, \text{ for all } k = 1, 2, \ldots, n \quad (3)$$

MEASURING LOS USING GIS

The process of measuring the LOS started with the preparation of criterion maps. All datasets were rasterised and reclassified to ensure comparability.

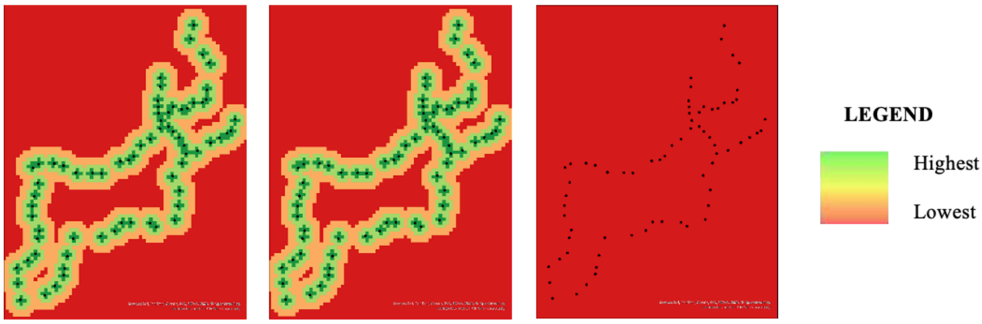


a) Health service area b) Institution area c) Commercial area d) Industrial area

e) Park and Ride f) Connectivity with other modes g) Accesibility for Disabled h) Basic Amenities

continue...

...cont.



i) Retail and service facility j) Comfort features k) Population

FIGURE 3. Criterion Maps

The rasterization process was conducted to convert vector data into raster format for the index modelling using weighted overlay analysis. During the process, each raster cell represents a geographic area with assigned value that indicates the level of accessibility of the area. Proximity-based analysis (Euclidean Distance) was used to derive the criterion maps for all other criteria except for population as the cells located nearer to geographic location of the criteria were assigned higher accessibility values, while cells farther from them received lower values.

The raster was then reclassified to standardize the proximity rasters into accessibility classes based using distance decay function as the accessibility will be reduced as the distance increases, subject to commonly practiced planning distances 400m, 800m and 1,500m. Figure 3 presents the criterion maps generated for each sub-criterion used in the AHP-GIS analysis.

Index modelling was then derived to model the LOS using Weighted Linear Combination (WLC) method that is defined by using Equation 4 (Malczweski, 2011).

$$V(A_i) = \sum_{k=1}^{n} w_k v(a_{ik}) \quad (4)$$

where $V(A_i)$ is overall value of the *i*-th alternative at location, s_i, defined by the (x_i, y_i) coordinates (for the sake of simplicity a single subscript, *i,* is used to indicate the location of the *i*-th alternative); $V(A_i)$ is the value of the *i*-th alternative with respect to the *k*-th attribute measured by means of the value function.

SPATIAL STATISTICAL ANALYSIS

To analyse spatial patterns, three statistical methods were applied: Average Nearest Neighbour (ANN), Global Moran's I, and Getis-Ord Gi* hotspot analysis. The LOS value from the index model at each station was extracted for this purpose.

ANN was used to evaluate the spatial distribution of the LRT stations by comparing the observed average distance between each point and its nearest neighbor to the expected average distance in a hypothetical random distribution.

On the other hand, Global Moran's I was used to measure spatial autocorrelation, which assesses whether features with similar LOS values are spatially clustered or randomly distributed across the study area. The method was used to determine whether LOS scores with similar values are grouped geographically.

Lastly, Getis-Ord Gi* identified localized clusters of high and low LOS scores, termed hotspots and cold spots, respectively.

The three analyses would help in understanding the spatial pattern of the LOS across the rail-transit network.

RESULTS AND DISCUSSION

WEIGHTAGE OF CRITERIA AND SUBCRITERIA

Table 3 shows the AHP weightage that had been derived for the criteria and their subcriteria. Accessibility accounts for 0.571 of the total weightages, significantly exceeding other criteria. For subcriteria, Connectivity with other modes and Park and Ride are the two most important aspect. The other two criteria, Service Quality and Landuse weighted similarly signify their needs in ensuring the LOS that will satisfy the demand.

TABLE 3. Weightage of Criteria and Sub-criteria

Criteria/Subcriteria	Weightage
LAND USE	0.138
Institution Area	0.037
Health Services Area Industrial	0.030
Area	0.008
Commercial Area	0.062
SERVICE QUALITY	0.135
Retail and Service Facilities	0.031
Basic Amenities	0.036
Comfort Features	0.015
Accessibility for Disabled	0.053
ACCESSIBILITY	0.571
Connectivity with other modes	0.431
Park and Ride	0.139
POPULATION	0.156

This finding is interesting and similar to previous studies as most of them often prioritise accessibility and connectivity to landuses as well as service quality. This suggests integration of operational efficiency with accessibility and connectivity measure could provide improvement in the framework of measuring the LOS which always consider the two independently as mentioned earlier.

SPATIAL VARIATIONS IN LOS DISTRIBUTION

The LOS assessment shown in Figure 4 reveals spatial variations in rail-transit performance across KL. Overall, all stations have good LOS resulting area around them to receive good services as compared to the ones further from them. The analysis indicates that areas with more integrated urban environments tend to provide more efficient and accessible transit services for daily commuters.

Stations that are located within the central urban corridor generally demonstrate higher LOS values due to stronger multimodal connectivity, better pedestrian accessibility, and closer proximity to commercial, institutional, and mixed-use developments. The stations benefit from integration with other public transport services and surrounding high-density urban activities, which contribute positively to overall accessibility and station functionality.

In contrast, stations located in suburban areas generally exhibit slightly lower LOS classifications which may be influenced by factors such as limited feeder transport services, less extensive pedestrian infrastructure, and lower concentrations of surrounding commercial and institutional activities.

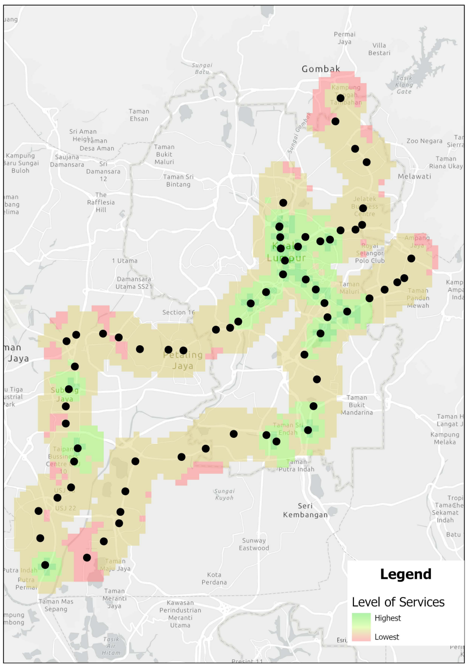


FIGURE 4. LOS Map

Overall, the findings highlight the importance of coordinated transport and land use planning in strengthening accessibility, improving connectivity, and promoting a more balanced distribution of transit service quality across the LRT network in KL.

SPATIAL DEPENDENCE AND CLUSTERING

The spatial statistical analyses indicate that LOS scores across LRT stations in KL exhibit statistically significant clustering patterns rather than random distribution. The

ANN analysis produced a Nearest Neighbor Ratio (NNR) of 0.751 indicating the LOS is clustered. On the other hand, the Global Moran's I analysis recorded a positive autocorrelation with a value of (0.438), confirming that stations with similar LOS characteristics tend to be spatially concentrated. These findings suggest that the distribution of LOS is closely associated with broader urban structure, accessibility, and surrounding land use patterns.

The hotspot analysis further revealed that higher LOS clusters are predominantly concentrated within the central urban corridor of KL, where transport integration, accessibility, and urban activities are more intensive. In contrast, relatively lower LOS clusters were identified in suburban areas located to the north, south, and west of the metropolitan region, where development intensity and multimodal connectivity are comparatively lower. These spatial patterns highlight the influence of urban context and accessibility on transit performance, while emphasizing the importance of integrated transport and land use planning in achieving a more balanced and accessible rail-transit network.

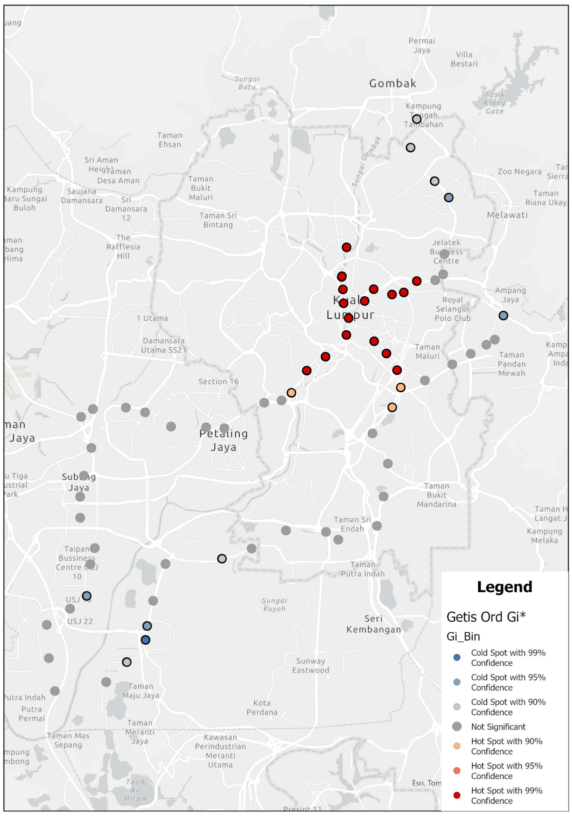


FIGURE 5. Spatial Pattern of LOS

VALIDATION AND MODEL RELIABILITY

Field verification confirms consistency between modelled LOS and real-world conditions. This supports the reliability of GIS-MCDA as a decision-support tool for transit evaluation. The field visits were conducted at selected nine stations to evaluate the LOS derived. The subcriteria on ground were carefully examined to see their influence on the LOS. Site verification revealed that multimodal integration, accessibility to commercial area, institution area, good pedestrian environment and disabled-friendly contributes to a higher LOS value.

In addition, expert's validation was obtained to ensure that the GIS-based LOS assessment accurately reflected on-the-ground realities and professional perspectives. According to the expert, the LOS classifications successfully captured the variation in service quality across different LRT stations, aligning well with their urban context and infrastructure provision.

The findings highlight several important implications for urban transport planning. First, improving first- and last-mile connectivity should be prioritised to enhance accessibility. Second, targeted interventions are required in peripheral areas where LOS remains low. Third, TOD strategies should emphasise connectivity and integration rather than density alone.

CONCLUSION

This study demonstrates that LOS in rail transit systems is fundamentally shaped by spatial and accessibility factors rather than operational characteristics alone. By integrating GIS and AHP, the study provides a comprehensive framework for evaluating service performance across stations. The results reveal significant spatial variations, with central areas benefiting from higher service levels due to better connectivity and land use integration. The strong spatial clustering observed suggests that infrastructure development follows existing urban advantages, reinforcing disparities. The proposed framework offers a practical tool for policymakers to identify priority areas for intervention. Future research should incorporate user-based data and explore dynamic temporal variations in LOS.

This study has several limitations. First, is the uncertainty in AHP weighing which may influence the expert's judgement. Second, the analysis relies primarily on spatial and expert-based data without incorporating user perception or behavioural data. Third, the study adopts a static approach and does not consider temporal variations in service performance. Future research should address these limitations by incorporating Fuzzy-AHP to address uncertainty, user-based surveys to incorporate end-user's perspective, and dynamic analysis.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Teknologi MARA for supporting and funding this study.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Alamri, S., Adhinugraha, K., Allheeib, N. & Taniar, D. 2023. GIS analysis of adequate accessibility to public transportation in metropolitan areas. *ISPRS International Journal of Geo-Information* 12(5): 180.

Bakar, M. F. A., Norhisham, S., Katman, H. Y., Fai, C. M., Azlan, N. N. I. M. & Samsudin, N. S. S. 2022. Service quality of bus performance in Asia: A systematic literature review and conceptual framework. *Sustainability* 14(13): 7998. https://doi.org/10.3390/su14137998

Bhellar, M. G., Talpur, M. A. H., Khahro, S. H., Ali, T. H. & Javed, Y. 2023. Visualizing travel accessibility in a congested city center: A GIS-based isochrone model and trip rate analysis considering sustainable transportation solutions. *Sustainability* 15(23): 16499.

Biswas, A., Adhinugraha, K. & Taniar, D. 2023. Comparative GIS analysis of public transport accessibility in metropolitan areas. *Computers* 12(12): 260.

Ibrahim, A. N. H., Borhan, M. N., Osman, M. H., Mat Yazid, M. R. & Md. Rohani, M. 2022. The influence of service quality on user's perceived satisfaction with light rail transit service in Klang Valley, Malaysia. *Mathematics* 10(13): 2213.

Ibrahim, S. M., Ayad, H. M., Turki, E. A. & Saadallah, D. M. 2023. Measuring transit-oriented development (TOD) levels: Prioritize potential areas for TOD in Alexandria, Egypt using GIS-Spatial Multi-Criteria based model. *Alexandria Engineering Journal* 67: 241–255.

Kåresdotter, E., Page, J., Mörtberg, U., Näsström, H. & Kalantari, Z. 2022. First mile/last mile problems in smart and sustainable cities: A case study in Stockholm County. *Journal of Urban Technology* 29(2): 115–137.

Malczewski, J. 2011. Local weighted linear combination. *Transactions in GIS* 15(4): 439–455.

Malczewski, J. & Rinner, C. 2015. *Multicriteria Decision Analysis in Geographic Information Science*. Berlin: Springer. https://doi.org/10.1007/978-3-540-74757-4

Naharudin, N., Salleh, A. H., Halim, A. M. & Latif, A. Z. 2020. Conceptual framework for walkability assessment for pedestrian access to rail transit services using spatial-MCDA. In *IOP Conference Series: Earth and Environmental Science* 540: 012023. https://doi.org/10.1088/1755-1315/540/1/012023

Pawar, S., Tandyekkal, A. & Gaddam, H. K. 2025. Point based system for assessing passenger level of service at public transport terminals: A railway case study. *Transportation Research Procedia* 82: 1753–1770.

Romero, C., Zamorano, C. & Monzon, A. 2023. Exploring the role of public transport information sources on perceived service quality in suburban rail. *Travel Behaviour and Society* 33: 100642.

Saaty, T. L. 1980. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. New York: McGraw-Hill. https://doi.org/10.21236/ADA214804

Salter, B. & Alexander, S. 2022. Getting there: The effect of first and last mile infrastructure and services on rail ridership. *Transportation Research Record* 2676(10): 402–412.

Tola, S. G. 2023. Assessment of pedestrian facilities accessibility at Addis Ababa light rail transit stations in case of east-west corridor. *International Journal of Mechanical Engineering and Applications* 11(6): 125–142.

Wan, T., Lu, W. & Sun, P. 2023. Equity impacts of the built environment in urban rail transit station areas from a transit-oriented development perspective: A systematic review. *Environmental Research Communications* 5(9): 092001.

Wang, M., Mao, B., Yang, Y., Shi, R. & Huang, J. 2022. Determining the level of service scale of public transport system considering the distribution of service quality. *Journal of Advanced Transportation* 2022(1): 5120401.