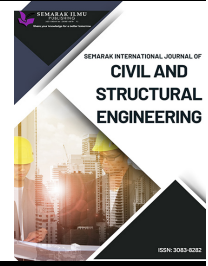




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A Comprehensive Review on Road Signboards Design Placement and Impact

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ABSTRACT

Road signboards played a critical role in road safety and traffic management by providing information, warnings, and guidance to road users. The expansion of transportation networks increased the demand for signboards that were clear, visible, and effective across diverse traffic environments. Previous studies examined signboard design, placement, and technological development largely in isolation, which limited understanding of how these elements collectively influenced road safety and user behaviour. This gap highlighted the need for a more comprehensive examination of road signboard effectiveness. This study aimed to review recent research on road signboard design, placement, and impact, with specific attention given to the application of intelligent systems and infrastructure. A systematic literature review was conducted in accordance with the PRISMA guidelines. Relevant journal articles were retrieved from the Scopus and ScienceDirect databases, and a structured screening process led to the selection of 32 eligible studies published between 2022 and 2025. The findings showed that sensing technologies and machine-learning approaches improved traffic sign detection and recognition, although their performance was influenced by data quality, environmental conditions, and regional variation. Signboard design and placement characteristics such as visibility, readability, and information load were found to strongly affect user comprehension and compliance. The review also indicated that intelligent infrastructure and supportive policy measures enhanced the effectiveness of road sign systems, particularly in complex traffic environments. In conclusion, the effectiveness of road signboards was shaped by the interaction between technological capability, human factors, and infrastructure planning. Improving road safety therefore required an evidence-based approach that considered these elements together within traffic system design and implementation.

1. Introduction

Road signboards are fundamental components of road infrastructure that provide regulatory, warning, and informational guidance to road users. Their primary function is to support safe and efficient traffic movement by improving situational awareness and assisting drivers in making timely

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and appropriate decisions. Effective road signboards help reduce uncertainty, minimise driver error, and support safe interactions between vehicles, pedestrians, and cyclists. The influence of sign visibility and clarity on driver attention, gaze behaviour, and cognitive workload, particularly under night-time driving conditions, was reported by *Fiolić et al.*, [5].

The effectiveness of road signboards is strongly influenced by both design and placement characteristics. Design-related factors such as colour, contrast, symbol clarity, text size, and information load affect visibility and comprehension across different road user groups. *Jamson and Mrozek* [7] and *Ben-Bassat et al.*, [1] reported that adherence to ergonomic design principles improves sign comprehension and reduces cognitive demand. Placement-related factors, including sign height, spacing, orientation, and the surrounding visual environment, further determine whether road users are able to detect and interpret signboards within the available reaction time. Poor design or inappropriate placement has been associated with increased cognitive load and delayed driver response, as observed by *Fiolić et al.*, [5], highlighting the need to consider these factors jointly.

Previous studies have also examined the influence of roadside visual elements on driver behaviour. Roadside advertising, in particular, has been identified as a source of visual clutter that may impair eye movement patterns and increase cognitive workload. *Oviedo-Trespalacios et al.*, [14] and *Mustapić et al.*, [13] reported that such visual distractions can affect driver attention, especially among younger drivers. However, crash-based analyses by *Yannis et al.*, [16] reported mixed findings regarding the direct relationship between roadside advertising and accident occurrence, suggesting that the safety impact of roadside visual stimuli depends on contextual, behavioural, and environmental factors.

In recent years, advances in sensing technologies and machine-learning methods have expanded research related to road signboards and roadside assets. Automated traffic sign detection and recognition systems were examined by *Mazón et al.*, [12], demonstrating improved accuracy in sign identification and information processing. Intelligent and adaptive traffic sign systems, including smart displays and integration with driver assistance technologies, were reported to enhance sign effectiveness in high-risk environments by *Kamal et al.*, [8]. Despite these developments, challenges related to standardisation, environmental variability, integration with existing infrastructure, and policy support continue to limit widespread implementation.

Table 1

Overview of technology innovation in road signboards for road safety enhancement

Aspect	Key Findings
Night-time Visibility	High visibility of road signs optimizes cognitive load and ensures timely information delivery, enhancing driver awareness and response [17].
Roadside Advertising	Roadside advertising acts as environmental clutter, impairing eye movement patterns and increasing cognitive workload, especially in young drivers [13,18]. Mixed results on direct correlation with road accidents [16].
Ergonomic Design	Adherence to ergonomic principles, such as standardization of colours and shapes, significantly improves road sign comprehension and reduces cognitive load [1,7].
Technological Innovations	Electronic and adaptive traffic signs, smart display controllers, and driver assistance systems enhance road sign effectiveness and prevent accidents in high-risk areas [11,12,19].

To summarise how previous studies have addressed key aspects of road signboard design and application, Table 1 provides an overview of selected literature focusing on night-time visibility, roadside advertising, ergonomic design, and technological innovations. The table highlights the diversity of research approaches and illustrates that existing studies have generally focused on

specific dimensions of road signboard effectiveness rather than their combined influence on road safety.

To further illustrate the structure of the research landscape, Figure 1 presents a concept map summarising major research themes identified from the literature, including impact assessment, placement strategies, and design principles. These themes reflect the multidisciplinary nature of road signboard research, encompassing human perception, eye-tracking, visual analysis, traffic operation, geographic context, aesthetics, geometric design, and integration with advanced driver assistance systems.

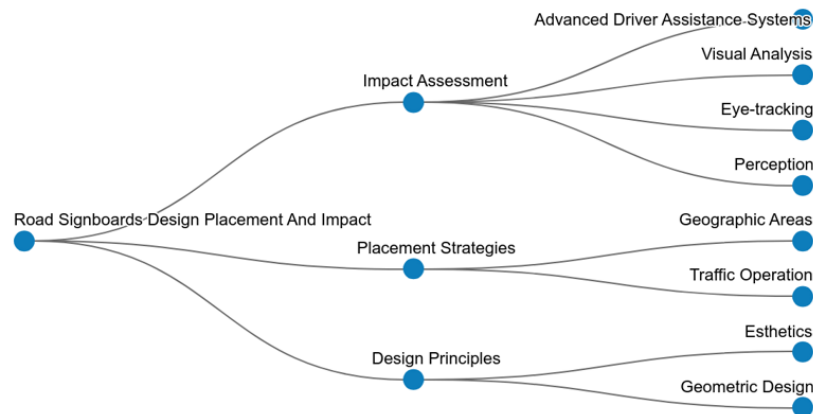


Fig. 1. Conceptual map of research themes in road signboard design, placement, and impact

Although research on road signboards has expanded considerably, several important gaps remain. Existing studies have largely examined design, placement, technological applications, or road user behaviour in isolation, with limited effort to synthesise their combined effects on road safety outcomes. Furthermore, recent work on sensing technologies and intelligent infrastructure has rarely been examined alongside human factors and policy considerations within a single review. This fragmentation limits the ability of researchers, practitioners, and policymakers to obtain a comprehensive understanding of current knowledge and unresolved challenges.

Addressing these gaps is important because road signboards continue to play a critical role in supporting safe traffic operation across diverse road users and traffic environments. A consolidated overview of existing evidence can assist in improving design standards, placement strategies, technology adoption, and infrastructure planning. Integrating findings from technical, behavioural, and system-level perspectives is therefore essential to support more informed decision-making aimed at enhancing road safety.

Therefore, the objective of this study was to conduct a systematic review of recent literature on road signboard design, placement, and impact on road safety. Specifically, this review aimed to:

- 1) classify existing studies on road signboard design and placement based on factors related to visibility, readability, comprehension, and road user behaviour
- 2) examine research trends related to sensing technologies, machine-learning approaches, and intelligent infrastructure applied to traffic signs and roadside assets
- 3) identify key findings, reported limitations, and research gaps in the current literature to inform future research directions related to road safety.

2. Methodology

2.1 Research Design

This study employed a systematic literature review (SLR) approach guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, as proposed by Page *et al.*, [15]. The PRISMA guidelines were adopted to ensure transparency, consistency, and reproducibility throughout the review process, particularly in the identification, screening, eligibility assessment, and data extraction of relevant studies. Adhering to this structured approach helped minimise selection bias and enhance the methodological rigor and reliability of the synthesised findings.

In accordance with the PRISMA framework, literature searches were conducted using two established academic databases, Scopus and ScienceDirect, selected for their comprehensive coverage of peer-reviewed research in engineering, transportation, safety sciences, and related interdisciplinary fields. The literature search was conducted in September 2025 using structured keyword combinations related to implementation, road signboard design, placement, effectiveness, and safety. To ensure relevance and currency, the search was limited to journal articles published between 2022 and 2025, written in English, and indexed under relevant subject areas.

The PRISMA process was applied systematically through four stages. The identification stage captured all potentially relevant records from the selected databases, yielding a total of 812 records, comprising 792 articles from Scopus and 20 articles from ScienceDirect. During the screening stage, titles and abstracts were reviewed to exclude studies that were not aligned with the review objective or fell outside the scope of road signboard design, placement, and safety impact. The eligibility stage involved full-text assessment to ensure that only relevant peer-reviewed journal articles meeting predefined inclusion criteria were retained. Finally, the data extraction stage involved systematically extracting and organising key information from the selected studies to support qualitative synthesis and thematic analysis.

The detailed search strings, Boolean operators, database field restrictions, publication year limits, document types, subject areas, and language filters applied in Scopus and ScienceDirect are presented in Table 2.

Table 2

The search string

Academic Database	Search string
Scopus	TITLE-ABS-KEY (("road signboard" OR "traffic sign") AND (design OR placement) AND (impact OR effectiveness OR safety)) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024) OR LIMIT-TO (PUBYEAR , 2025)) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "SOCL")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English")) Date of Access: September 2025
Science Direct	(road signboard traffic sign) AND (design placement) AND (impact effectiveness safety) Date of Access: September 2025

2.2 Data Screening

The screening stage, as the second phase of the PRISMA-guided systematic literature review, was conducted to refine the initially identified records and retain studies that were relevant to the review objective. During this stage, titles and abstracts were examined against predefined inclusion and exclusion criteria to remove records that did not meet the scope or quality requirements of the study.

A total of 686 records were excluded based on the following criteria: publications not written in English, studies published prior to 2022, non-journal literature (conference proceedings, books, or review articles), articles still in press, and studies outside the primary subject areas of engineering, social sciences, and computer science. These criteria were applied to ensure the inclusion of recent, peer-reviewed research that reflects current practices and perspectives related to road signboard design, placement, and safety impact. Following the screening process, 116 articles from Scopus and 10 articles from ScienceDirect were retained, resulting in a total of 126 studies for subsequent eligibility assessment. No duplicate records were identified during this stage. The detailed inclusion and exclusion criteria applied during the screening process are summarised in Table 3.

The study selection process followed the PRISMA framework and involved identification, screening, eligibility assessment, and final inclusion stages. An initial search retrieved 812 records from the selected databases, comprising 792 articles from Scopus and 20 articles from ScienceDirect. Following title and abstract screening based on predefined inclusion and exclusion criteria, 126 articles remained for full-text evaluation. After assessing full-text availability and relevance to the research objectives, 32 primary studies were selected for qualitative synthesis. The overall selection procedure is illustrated in the PRISMA flow diagram shown in Figure 2.

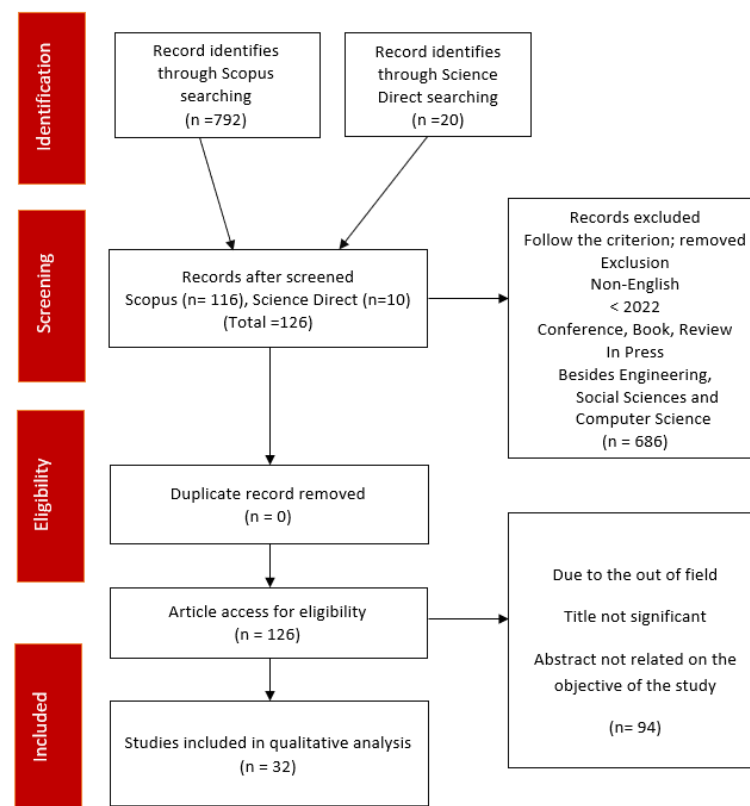


Fig. 1. Flow diagram of the proposed searching study

The inclusion and exclusion criteria applied during the screening stage are summarised in Table 3. These criteria were defined to ensure that the reviewed studies were relevant, current, and methodologically appropriate for addressing the research objective. Only peer-reviewed journal articles published in English between 2022 and 2025 were considered, while non-journal literature, articles still in press, and studies published prior to 2022 were excluded. In addition, the screening was restricted to studies indexed within the subject areas of engineering, social sciences, and computer science to capture the technical, behavioural, and computational perspectives relevant to road signboard design, placement, and safety impact. The consistent application of these criteria enabled a systematic reduction of records and ensured that only studies meeting the predefined scope and quality requirements progressed to the eligibility assessment stage.

Table 3
Inclusion and exclusion criteria applied during the screening stage

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2022 – 2025	< 2022
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press
Subject Area	Engineering, Social Sciences and Computer Science	Besides Engineering, Social Sciences and Computer Science

2.3 Eligibility

At the eligibility stage of the PRISMA-guided systematic literature review, the 126 articles that passed the screening stage were subjected to full-text assessment to determine their relevance and suitability for inclusion. This stage focused on evaluating the extent to which each study aligned with the research objective related to road signboard design, placement, and impact on road safety.

Following full-text evaluation, 95 articles were excluded for specific reasons. These included full-text unavailability, lack of direct relevance to road signboard design or placement, disciplinary misalignment, titles with limited substantive relevance, and abstracts that did not adequately address the objectives of the review. Studies that failed to contribute meaningful insights into the focus of this review were excluded to maintain analytical coherence.

As a result of the eligibility assessment, a final set of 31 articles met all inclusion criteria and were retained for qualitative synthesis. This refined selection ensured that the evidence base consisted of studies that were accessible, thematically aligned, and methodologically appropriate for addressing the research questions of this review.

2.4 Data Abstraction and Analysis

An integrative analysis approach was adopted to synthesise evidence from the studies included in this systematic literature review and to identify key themes related to road signboard design, placement, and impact. Following the eligibility assessment, data were systematically abstracted from the 31 included articles. The abstraction process focused on extracting essential information from each study, including authorship, publication year, research focus, methodological approach, and source database.

The extracted data were organised and compared across studies to identify recurring patterns, similarities, and differences within the literature. Based on this comparison, overarching themes and subthemes were developed to represent the main research directions and findings. To ensure analytical consistency and credibility, the thematic structure was refined through iterative discussion among the authors, with discrepancies in interpretation resolved through consensus.

The compiled details of the included primary studies, including bibliographic information and database sources, are summarised in Table 4, which provides a structured overview of the evidence base used for the integrative analysis.

Table 4
 Number and details of primary studies database

No	Authors	Title	Year	Journal	Scopus	Science direct
1	K.K., Kenney, Kenneth K.; E., Che, Erzhuo	Investigating the Impact of Training a Data Set Selection for Pole-Like Object Classification in Mobile Laser Scanning Data	2025	Journal of Surveying Engineering, - ASCE	/	
2	J., Wang, Jiayue; L., Shen, Liangchang; H., Wang, Huanyu; R., Lovreglio, Ruggiero; Y., Tong, Yunhe	An empirical investigation on the impact of evacuation signages on individual behaviour in building evacuations	2025	Journal of Building Engineering	/	
3	P.J., Ossenbruggen, Paul J.	Traffic Planning, Safety, Roundabouts, the Public, and Control Theory	2025	Journal of Transportation Engineering Part A: Systems	/	
4	Y., Cui, Yang; Y., Han, Yi; D., Guo, Dong	TS-DETR: Multi-scale DETR for traffic sign detection and recognition	2025	Pattern Recognition Letters	/	
5	J., Huo, Junyu; X., Wang, Xuesong; Q., Liu, Qian; Z., Wang, Zhongren; X., Zhu, Xiaolei	Analysis of Factors Influencing Traffic Sign Recognition Based on Multi-Sensor Perception Data	2025	Transportation Research Record	/	
6	J., Mei, Jialin; Z., Du, Zhigang; P., Wu, Pengfei	Effects of delineation signs on driving behavior in expressway tunnel curves	2025	Traffic Injury Prevention	/	
7	Y., Meng, Yunwei; L., Wang, Lei; Y., Zhang, Yin; B., Li, Binbin; Z., Liu, Zhongshuai; G., Qing, Guangyan; F., Chen, Fang	Driving visual information in highway tunnel entrances: A computational method based on optical flow and color quantification	2025	Traffic Injury Prevention	/	
8	Y., Hu, Yaqi; F., Wang, Fei; D., Ye, Dongdong; M., Wu, Maoqiang; J., Kang, Jiawen; R., Yu, Rong	LLM-Based Misbehavior Detection Architecture for Enhanced Traffic Safety in Connected Autonomous Vehicles	2025	IEEE Transactions on Vehicular Technology	/	
9	F.E., Khalloufi, Fatima Ezzahra; N., Rafalia, Najat; J., Abouchabaka, Jaafar	Customized convolutional neural networks for Moroccan traffic signs classification	2024	Indonesian Journal of Electrical Engineering and Computer Science	/	

10	J., Zhou, Jialu; N., Ujang, Norsidah	An Analysis of Pedestrian Preferences for Wayfinding Signage in Urban Settings: Evidence from Nanning, China	2024	Buildings	/
11	R., Li, Rongzhen; Y., Chen, Yajun; Y., Wang, Yu; C., Sun, Chaoyue	YOLO-TSF: A Small Traffic Sign Detection Algorithm for Foggy Road Scenes	2024	Electronics (Switzerland)	/
12	Y., Kwon, Yong-hwa; Y., Kwon, Youngbeom; D.C., Nwagbala, Daniel Chukwunonso; J., Park, Jongyil	The Cognitive Load Limits of Multiple Safety Signs	2024	Buildings	/
13	S., von Beesten, Silke; A., Bresges, André	The effectiveness of teaching methods for preparing teacher education students to teach road safety-related content	2024	Frontiers in Education	/
14	T., Walelign Bishaw, Temesgen; G., Nurye, Gebrechiristos; R.B., Singh, Ranavijai Bahadur	Investigating factors of pedestrian safety using ordinal logistic regression in Addis Ababa City roads	2024	Frontiers in Sustainable Cities	/
15	N.A., Malek, Nada Ahmed; R.F., Boudour, Rachid Farfar	TariqAmn's Innovative Road Safety Paradigm through Smart Technology	2024	Periodica Polytechnica Transportation Engineering	/
16	M., Lippert, Moritz; F., Glatzki, Felix; H., Winner, Hermann	Behavior-Semantic Scenery Description (BSSD) of Road Networks for Automated Driving	2024	IEEE Access	/
17	Y., Yang, Yanqun; X., Liu, Xianhui; S.M., Easa, Said M.; L., Huang, Lina; X., Zheng, Xinyi	Impact of roadside advertisements near traffic signs on driving safety	2024	Transportation Research Part F: Traffic Psychology and Behaviour	/
18	W., Li, Wenjie; C., Wang, Chenzhu; F., Chen, Fei; D., Zhang, Danni; S.M., Easa, Said M.; J., Cheng, Jianchuan	Developing Character Height Model for Tibetan-Chinese Bilingual Guide Signs Using Driving Simulation	2023	Journal of Transportation Engineering Part A: Systems	/
19	W., Cao, Weipeng; Y., Wu, Yuhao; C., Chakraborty, Chinmay; D., Li, Dachuan; L., Zhao, Liang; S.K., Ghosh, Soumya Kanti	Sustainable and Transferable Traffic Sign Recognition for Intelligent Transportation Systems	2023	IEEE Transactions on Intelligent Transportation Systems	/
20	Y., Pei, Yaowen; F., Chen, Feng; T., Ma, Tao; P., Peng, Peng; G., Gu, Gonghui; Y., Ji, Yuxuan	Towards a novel magnetic asphalt mixture containing ceramic ferrites for intelligently encoding road traffic sign information	2023	Construction and Building Materials	/

21	C., Lai, Chihchun; T.Y., You, Ting Yun	Graphic traffic signals—The color design of 3D crosswalks	2023	Transportation Research Part F: Traffic Psychology and Behaviour	/
22	S., Zhu, Sicong; H., Yue, Hao; T., Suzuki, Tatsuto; I., Kim, Inhi; L., Yu, Lei; Q., Lan, Qing	A UWB/INS Trajectory Tracking System Application in a Cycling Safety Study	2023	Sensors	/
23	R.E., Dewar, Robert E.; M., Pronin, Monica	Designing road sign symbols	2023	Transportation Research Part F: Traffic Psychology and Behaviour	/
24	D., Zhang, Dajun; W., Shi, Wei; M., St-Hilaire, Marc; R., Yang, Ruizhe	Blockchain-Based Intelligence Networking for Cooperative Positioning Towards Future Internet of Vehicles	2023	IEEE Transactions on Vehicular Technology	/
25	Q., Zhao, Qian; W., Guo, Weifeng	Small object detection of imbalanced traffic sign samples based on hierarchical feature fusion	2023	Journal of Electronic Imaging	/
26	Z.N., Aldoski, Ziyad N.; C., Koren, Csaba	Impact of Traffic Sign Diversity on Autonomous Vehicles A Literature Review	2023	Periodica Polytechnica Transportation Engineering	/
27	M.S., Sarker, M. Shaheen; O.M., Carsten, Oliver M.J.; Y., Huang, Yue; F., Hajiseyedjavadi, Foroogh	Motivations of pedestrians for safe use of highway crossing: an application of the behaviour change model COM-B in Bangladesh	2023	Traffic Safety Research	/
28	D., Maulina, Dewi; D.Y., Irwanda, Diandra Yasmine; S., Audinia, Shabrina; S.P., Nandini, Satwika Parama; D.T., Indirasari, Dyah Triarini	How supplementary sign features can improve traffic safety among motorcyclists? The effect of capitalization and information length on road sign comprehension	2023	Traffic Injury Prevention	/
29	D., Maulina, Dewi; E.S., Siregar, Ermanda Saskia; T.A., Rachma, Titis Alocitta; S.A., Nashria, Sry Ayu; D.Y., Irwanda, Diandra Yasmine	How effective is training for improving traffic sign comprehension? Examining the interaction between training and sign type among motorcyclists	2022	IATSS Research	/
30	X., Ren, Xinyue; W., Zhang, Weiwei; M., Wu, Minghui; C., Li, Chuanchang; X., Wang, Xiaolan	Meta-YOLO: Meta-Learning for Few-Shot Traffic Sign Detection via Decoupling Dependencies	2022	Applied Sciences (Switzerland)	/
31	Y., Tang, Yiwen; J., Zhang, Jiaxin; R., Liu, Runjiao; Y., Li, Yunqin	Exploring the Impact of Built Environment Attributes on Social Followings Using Social	2022	ISPRS International Journal of Geo-Information	/

Media Data and Deep Learning

32	Rachakonda, Y., & Pawar, D. S.	Assessing effectiveness of intersection conflict warning system on driving performance under obstructed line of sight at unsignalized intersection	2025	Traffic Psychology and Behaviour	/
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2.4 Quality Appraisal

In accordance with the guidelines proposed by Kitchenham and Charters [9], a quality appraisal was conducted after the selection of primary studies to assess the methodological robustness and relevance of the included research. Quality assessment is a critical step in systematic literature reviews, as it enables the evaluation and comparison of studies based on predefined and transparent criteria. In this study, the quality appraisal framework proposed by Anas Abouzahra *et al.*, [20] was adopted. This framework comprises six quality assessment (QA) criteria, designed to evaluate the clarity, methodological soundness, and analytical contribution of each included study. Each criterion was independently assessed using a three-point scoring scale: “Yes” (Y) was assigned a score of 1 when the criterion was fully satisfied, “Partly” (P) was assigned a score of 0.5 when the criterion was partially met, and “No” (N) was assigned a score of 0 when the criterion was not met.

To enhance objectivity and reduce individual bias, the quality appraisal was performed by three independent experts. The scores assigned for each criterion were then consolidated to provide an overall quality profile for each study. This systematic appraisal process ensured that the evidence base used in the review was not only relevant but also methodologically sound and suitable for qualitative synthesis.

3. Results

Based on the quality assessment, Table 2 presented the assessment performance of the selected primary studies included in this review. The evaluation of the 32 primary studies revealed that the majority achieved high scores across the six assessment criteria, particularly in terms of clearly stated research objectives, clearly described research methods, and well-defined concepts. As shown in Table 2, many of the assessed studies recorded quality assessment scores ranging from 83.3% to 91.7%. Several studies, including PS5 and PS20, achieved a perfect score of 100%. However, a recurring weakness observed across several studies was the incomplete discussion of research limitations and partial comparison with existing literature. This issue was evident in studies such as PS3, PS10, PS21, and PS27. PS31 recorded the lowest score (75%), primarily due to the absence of limitation reporting.

From the analysis, three overarching themes were identified to represent the main patterns observed across the selected studies. The first theme, Sensing and Machine Learning for Traffic Sign and Roadside Asset Perception, encompassed studies that focused on the use of artificial intelligence, deep learning techniques, and sensor-based technologies for traffic sign detection and recognition. The second theme, Design, Placement, and Human Factors of Signage, included studies that examined visual design features, sign placement, and human perceptual and cognitive responses in relation to the effectiveness of road signboards for drivers, pedestrians, and cyclists. The third theme,

Intelligent Infrastructure, Systems Integration, and Policy for Road Safety, comprised studies that addressed the application of smart infrastructure, system integration, and regulatory or policy-related aspects in road safety research.

Table 2
 Quality assessment table for the selected papers

Author	Title	QA1	QA2	QA3	QA4	QA5	QA6	Total Mark	%
PS1	Investigating the Impact of Training a Data Set Selection for Pole-Like Object Classification	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	P (0.5)	5.0	83.3%
PS2	Impact of Evacuation Signages on Individual Behaviour	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS3	Traffic Planning, Safety, Roundabouts, and Control Theory	Y (1)	Y (1)	P (0.5)	P (0.5)	Y (1)	P (0.5)	4.5	75.0%
PS4	TS-DETR: Multi-scale DETR for Traffic Sign Detection and Recognition	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS5	Factors Influencing Traffic Sign Recognition Based on Multi-Sensor Data	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	6.0	100%
PS6	Effects of Delineation Signs on Driving Behavior in Expressway Tunnel Curves	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS7	Driving Visual Information in Highway Tunnel Entrances	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	Y (1)	5.5	91.7%
PS8	LLM-Based Misbehavior Detection for Enhanced Traffic Safety	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	P (0.5)	5.0	83.3%
PS9	Customized CNN for Moroccan Traffic Signs Classification	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS10	Pedestrian Preferences for Wayfinding Signage in Urban Settings	Y (1)	Y (1)	P (0.5)	Y (1)	P (0.5)	P (0.5)	4.5	75.0%
PS11	YOLO-TSF: A Small Traffic Sign Detection Algorithm for Foggy Road Scenes	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS12	The Cognitive Load Limits of Multiple Safety Signs	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	Y (1)	5.5	91.7%

PS13	Effectiveness of Teaching Methods for Road Safety Education	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	P (0.5)	5.0	83.3%
PS14	Investigating Factors of Pedestrian Safety in Addis Ababa	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS15	TariqAmn's Innovative Road Safety Paradigm	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS16	Behavior-Semantic Scenery Description (BSSD) for Automated Driving	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	P (0.5)	5.0	83.3%
PS17	Impact of Roadside Advertisements near Traffic Signs on Driving Safety	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS18	Developing Character Height Model for Tibetan-Chinese Bilingual Guide Signs	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	P (0.5)	5.0	83.3%
PS19	Sustainable and Transferable Traffic Sign Recognition for ITS	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS20	Novel Magnetic Asphalt Mixture for Encoding Road Traffic Sign Information	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	6.0	100%
PS21	Graphic traffic signals: The color design of 3D crosswalks	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	P (0.5)	5.0	83.3%
PS22	A UWB/INS Trajectory Tracking System Application in a Cycling Safety Study	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS23	Designing road sign symbols	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS24	Blockchain-Based Intelligence Networking for Cooperative Positioning	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS25	Small object detection of imbalanced traffic sign samples	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS26	Motivations of pedestrians for safe	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	Y (1)	5.5	91.7%

	use of highway crossing (COM-B model in Bangladesh)								
PS27	Impact of Traffic Sign Diversity on Autonomous Vehicles (Review)	Y (1)	Y (1)	P (0.5)	Y (1)	Y (1)	P (0.5)	5.0	83.3%
PS28	How supplementary sign features can improve traffic safety among motorcyclists	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS29	How effective is training for improving traffic sign comprehension	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS30	Meta-YOLO: Few-Shot Traffic Sign Detection	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%
PS31	Exploring the Impact of Built Environment Attributes on Social Followings Using Social Media Data and Deep Learning	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	N (0)	4.5	75.0%
PS32	Assessing effectiveness of intersection conflict warning system on driving performance	Y (1)	Y (1)	Y (1)	Y (1)	Y (1)	P (0.5)	5.5	91.7%

3.1 Sensing and Machine-Learning for Traffic Sign / Roadside Asset Perception

Studies grouped under this theme examined sensing technologies, machine-learning models, and dataset strategies for traffic sign and roadside asset detection. Several studies reported that data quality, dataset diversity, and representation of degraded or rare classes influenced detection performance. Kenney and Che reported improved classification accuracy for pole-like assets when models were trained using mobile laser scanning data from diverse urban and rural environments [21]. Huo *et al.*, [6] identified environmental and design-related factors such as sign position, lighting, blockage, cleanliness, fading, and reflectivity as contributors to perception failure in automated systems. Aldoski and Koren reported that traffic sign diversity across regions limited model transferability due to variations in shape, colour, and information content [22].

Other studies focused on model architecture and representation strategies. Cui *et al.*, [3] reported higher detection and recognition rates using a multi-scale DETR architecture compared with several YOLO-based models. Khalloufi *et al.*, [8] reported high classification accuracy using a customised convolutional neural network optimised for a region-specific dataset. Cao *et al.*, [2] reported improved cross-dataset performance using a joint semantic representation approach that combined prior knowledge with data-driven features.

Several studies addressed robustness under adverse conditions and class imbalance. Li *et al.*, [10] reported improved detection performance in foggy environments using a customised YOLO-based model and a dedicated foggy dataset. Zhao and Guo reported effective detection of small and imbalanced traffic sign samples using hierarchical feature fusion [23]. Ren *et al.*, [24] reported improved few-shot detection performance using a meta-learning framework.

3.2 Design, Placement and Human Factors of Signage

Studies within this theme examined visual design characteristics, placement strategies, and user responses to road signage. Wang *et al.*, [25] reported that elevated wall-mounted evacuation signs reduced evacuation time, while ground-level signs improved route adherence during emergency situations. Mei *et al.*, [26] reported that delineation signs influenced driving speed and lane stability in tunnel curves. Meng *et al.*, [27] quantified the relationship between environmental visual information and drivers' visual workload, reporting associations between signage density and driving comfort.

Several studies examined perception and comprehension. Zhou and Ujang reported that pedestrian preferences for wayfinding signage were influenced by aesthetic and cultural factors [28]. Li *et al.*, [10] reported that character height and aspect ratio affected recognition efficiency in bilingual guide signs. Dewar and Pronin identified recurring issues related to symbol size, contrast, and line width that affected comprehension [29]. Maulina *et al.*, [30] reported that supplementary sign features and targeted training improved motorcyclists' comprehension of traffic signs.

Other studies examined cognitive load and environmental distractions. Kwon *et al.*, [31] reported increased cognitive load associated with excessive safety signage, while Yang *et al.*, [32] reported reduced sign recognition when roadside advertisements were placed near traffic signs [32]. Lai and You reported improved pedestrian visibility using three-dimensional crosswalk designs [33]. Sarker *et al.* reported associations between signage, infrastructure design, and pedestrian behaviour using the COM-B model [34].

3.3 Intelligent Infrastructure, Systems Integration and Policy for Road Safety

Studies under this theme focused on intelligent traffic systems, infrastructure innovation, and integrated safety solutions. Ossenbruggen reported safety benefits associated with roundabout design [35]. Malek and Boudour reported reduced traffic incidents through the deployment of intelligent traffic signage integrated with sensing technologies [11]. Hu *et al.*, [19] reported successful detection of misbehaviour in connected autonomous vehicle environments using a large language model-based framework.

Other studies examined infrastructure-level innovations. Lippert *et al.* reported improved safety validation for automated driving through behaviour-semantic scenery descriptions [36]. Pei *et al.*, [37] reported durable and cost-efficient magnetic asphalt materials for encoding traffic sign information. Zhang *et al.*, [38] reported improved vehicle positioning accuracy using blockchain-based cooperative networking. Zhu *et al.*, [39] reported precise cyclist trajectory tracking using an integrated UWB/INS system for safety evaluation.

4. Conclusions

In conclusion, this systematic literature review addressed the research objective of consolidating and evaluating recent studies on road signboard design, placement, and impact in relation to road safety and traffic efficiency. Using a PRISMA-guided selection process, 32 primary studies were identified and synthesised. The findings showed that current research on road signboards consistently examines three interconnected areas, namely sensing and machine-learning approaches for traffic sign and roadside asset perception, design and placement factors influencing user comprehension and behaviour, and the integration of intelligent infrastructure and systems for road

safety applications. The reviewed studies reported that sensing and learning-based approaches support traffic sign detection and recognition, while visual clarity, spatial positioning, and human cognitive considerations influence user response and compliance. The findings also showed that intelligent infrastructure and system integration are increasingly examined as part of road signboard effectiveness within modern transportation environments. Overall, the results respond directly to the research objective by clarifying how road signboard effectiveness has been investigated through technological approaches, human-related design factors, and integrated system perspectives in recent literature.

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