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Assessment of User-Perceived Level of Service at Signalized Intersections: A Review

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Abstract: Level of Service (LOS) is commonly applied as an indicator to assess the performance and operating quality of signalized intersections. Conventional LOS evaluation methods, such as those described in the Highway Capacity Manual (HCM) and the Indian Highway Capacity Manual (Indo-HCM 2017), mainly depend on operational parameters including control delay and saturation flow rate. In heterogeneous traffic environments typical of Indian cities, these operational indicators alone are insufficient to represent the actual experience and satisfaction of road users. Consequently, recent research has increasingly explored perception-based LOS approaches that consider the subjective responses of both motorists and pedestrians. This study reviews earlier work related to perceived LOS modelling, covering motorist-oriented models, pedestrian-focused assessments, and the use of intelligent classification techniques. Through this review, a significant research gap is identified: existing studies rarely address pedestrian–motorist interaction within a single integrated LOS framework at intersections. The study therefore highlights the need for a comprehensive perception-based LOS model that evaluates the combined experience of different road users under heterogeneous traffic conditions.

Index Terms **- Level of Service (LOS), Perceived Level of Service, Signalized Intersections, Heterogeneous Traffic, Pedestrian–Motorist Interaction, User Perception, Traffic Operations, Intelligent Classification Methods.**

I. INTRODUCTION

Signalized intersections represent important components of urban transportation networks where the movements of vehicles and pedestrians converge and interact. The operational quality of these locations significantly influences traffic efficiency, roadway safety, and the overall experience of users. Traditionally, the performance of intersections has been assessed through the Level of Service (LOS) concept, which categorizes traffic operating conditions from A (most favourable conditions) to F (least favourable conditions).

The LOS framework originally presented in the Highway Capacity Manual (HCM) and later adapted for Indian conditions in the Indian Highway Capacity Manual (Indo-HCM 2017) primarily depends on operational indicators such as average control delay and saturation flow. Although these indicators provide quantifiable standards for evaluating traffic performance, the methodology is predominantly oriented toward vehicular movement.

In heterogeneous traffic environments commonly observed in Indian cities, intersections operate as shared spaces containing different vehicle categories, frequent pedestrian crossings, and inconsistent lane discipline. Within such conditions, operational delay alone cannot adequately reflect the level of satisfaction experienced by users. Elements such as perceived safety, pedestrian–vehicle interaction, signal visibility, and intersection geometry also influence the perceived quality of service. As a result, recent studies have increasingly emphasized perception-based LOS assessment in order to better represent user experience at intersections.

The Indian Highway Capacity Manual (Indo-HCM 2017) defines LOS at signalized intersections mainly on the basis of average control delay per vehicle. Specific threshold values are used to classify intersections into service levels ranging from A to F. Although Indo-HCM adjusts operational parameters to accommodate Indian traffic characteristics, the framework still remains largely vehicle-oriented. Table 1 presents the structure and limitations of the conventional LOS framework.

While operational LOS provides an objective indication of traffic performance, it does not fully represent the experiential aspect of intersection usage. Two intersections that show similar delay values may generate very different levels of user satisfaction depending on safety conditions, pedestrian convenience, and surrounding environmental characteristics. This limitation forms the foundation for perception-based LOS research.

Table 1. Summary of Conventional LOS Framework

Aspect	HCM / Indo-HCM Approach	Limitation in Heterogeneous Traffic
Primary Indicator	Control delay per vehicle	Ignores pedestrian perception
Classification	A–F based on delay thresholds	Deterministic, not perception-based
User Focus	Motorists	Pedestrians evaluated separately
Interaction Consideration	Not integrated	No pedestrian–motorist interaction modelling
Environmental Factors	Minimal	Safety and comfort excluded

II. LITERATURE REVIEW

The concept of Level of Service (LOS) has traditionally been associated with evaluating operational traffic performance. The Highway Capacity Manual (HCM) defined LOS as a qualitative description of traffic conditions derived mainly from quantitative indicators such as average control delay, travel speed, and traffic density. When these methods were adapted for Indian conditions through the Indian Highway Capacity Manual (Indo-HCM 2017), the basic operational framework was preserved while certain parameters were modified to represent heterogeneous traffic characteristics.

However, conventional operational LOS assumes that delay is the primary factor determining service quality. This assumption indirectly treats efficiency as equivalent to user satisfaction. In heterogeneous traffic environments, particularly in developing nations, intersections function under complicated behavioural conditions that include weak lane discipline, frequent pedestrian crossings, diverse vehicle dimensions, and irregular signal compliance. Under such situations, operational indicators cannot fully represent the experiential quality perceived by road users.

The difference between measured operational performance and perceived user satisfaction has therefore encouraged a transition toward perception-based LOS modelling. Instead of depending exclusively on delay thresholds, perception-oriented approaches attempt to incorporate subjective assessments related to comfort, safety, and travel convenience.

2.1 Evolution from Operational LOS to Perceived LOS

Level of Service (LOS) has long been applied to assess the operational functioning of urban intersections. The concept was first presented in the Highway Capacity Manual (HCM) and subsequently adapted for Indian traffic environments in the Indian Highway Capacity Manual (Indo-HCM 2017). Within these frameworks, LOS categories are mainly defined using operational indicators including average control delay, saturation flow rate, and traffic volume.

Although operational LOS offers standardized indicators for evaluating traffic performance, it largely reflects vehicular efficiency rather than the overall experience of users. In heterogeneous traffic settings, particularly within developing countries, intersections accommodate mixed vehicle types, inconsistent lane discipline, and frequent pedestrian activity. In such circumstances, operational delay alone cannot completely describe perceived service quality. Elements such as safety, comfort, signal visibility, and pedestrian–vehicle interaction play an important role in shaping user satisfaction. Consequently, recent research has increasingly emphasized perception-based LOS modelling.

2.2 Motorist Perceived Level of Service Studies

Research on motorist-perceived Level of Service (LOS) has increasingly sought to integrate driver experience into the assessment of intersection performance instead of depending only on operational indicators. These investigations explore how motorists interpret traffic conditions by considering factors such as delay, traffic composition, and specific intersection characteristics.

One influential study in this field analyzed motorist perception under mixed traffic environments through field surveys combined with regression analysis. The findings showed that operational variables including control delay and traffic volume strongly affect how drivers evaluate service quality. However, the research also indicated that LOS classifications defined by Indo-HCM do not always align with driver satisfaction, implying that traditional operational measures may sometimes overestimate the actual quality of service in heterogeneous traffic environments [12].

Subsequent studies broadened this perspective by examining variations among different vehicle categories. The analysis revealed that perception differs across user groups such as two-wheeler riders, car drivers, and operators of heavy vehicles. In particular, two-wheeler users were observed to be more sensitive to changes in delay and to the presence of buses and trucks within the traffic stream [13].

Other researchers have assessed motorist service quality through simulation-based approaches. These investigations analyzed the influence of factors such as queue length, signal cycle duration, and turning movements on perceived intersection performance. Although simulation techniques provide detailed operational insights, they frequently lack direct feedback from drivers and therefore cannot completely capture subjective perception. Furthermore, pedestrian interactions are seldom incorporated within these modelling frameworks [7]…

Table 2. Motorist-Specific Influencing Factors Identified in Perceived LOS Studies

Sl. No.	Influencing Factor	Description	Type of Factor	Frequency in Literature	Impact on Perceived LOS
1	Control Delay	Average waiting time experienced by motorists at signal	Operational	Very High	Direct negative impact when increased
2	Delay Variability	Fluctuation in delay across cycles	Operational	High	High variability reduces satisfaction
3	Queue Length	Number of vehicles in queue at approach	Operational	High	Longer queues reduce comfort
4	Traffic Volume	Number of vehicles per unit time	Operational	High	Higher volume increases stress
5	Heavy Vehicle Percentage	Proportion of buses and trucks	Traffic Composition	High	Reduces manoeuvrability and comfort
6	Signal Cycle Length	Total time of signal cycle	Control Parameter	Moderate	Longer cycles increase perceived delay
7	Green Time Allocation	Duration of effective green time	Control Parameter	Moderate	Insufficient green reduces satisfaction
8	Turning Conflicts	Conflicts during right/left turns	Safety	High	Increases perceived risk
9	Pedestrian Interference	Crossing activity affecting vehicle movement	Interaction	Moderate	Reduces manoeuvrability
14	Visibility of Signal	Clarity of signal head visibility	Environmental	Moderate	Poor visibility increases uncertainty
15	Road Surface Condition	Pavement smoothness near intersection	Physical	Low–Moderate	Poor condition reduces comfort

2.3 Pedestrian-Specific Perceived LOS Studies

Pedestrian Level of Service (PLOS) research has gradually moved from traditional density-based evaluation methods toward approaches that emphasize pedestrian perception and travel experience. Contemporary assessments concentrate on how pedestrians perceive safety, comfort, accessibility, and ease of movement when crossing or walking near intersections. At signalized intersections, pedestrian satisfaction is influenced not only by operational factors such as waiting time or signal delay. Safety-related and environmental elements including vehicle speed, turning maneuvers, traffic volume, and the geometric design of crossing facilities also contribute significantly. Together, these aspects shape how pedestrians evaluate the overall quality of intersection operations.

Studies related to pedestrian infrastructure indicate that the physical characteristics of walking space strongly influence perceived comfort and safety. Variables such as walkway width, pedestrian flow intensity, and the level of separation between pedestrians and vehicular traffic affect the walking environment. When walking areas are narrow, obstructed, or shared with vehicles, pedestrians frequently perceive the environment as unsafe and uncomfortable. Likewise, limited buffer distance from moving vehicles or poorly maintained surfaces can decrease perceived service quality. Investigations of signalized crosswalks also identify several operational factors that influence pedestrian perception, including signal waiting time, available crossing duration, pedestrian crowding, and conflicts with turning vehicles. Among these variables, waiting time consistently appears as one of the most significant determinants of pedestrian satisfaction, because extended delays may lead to frustration and unsafe crossing behaviour [10].

Several investigations also demonstrate that pedestrian perception varies among different user groups. Individual characteristics such as age, physical capability, and travel purpose can influence how pedestrians assess intersection conditions. Elderly pedestrians, for instance, often show greater concern about vehicle speed, crossing distance, and the visibility of traffic signals, since these factors directly influence their perceived safety during crossing [14]. In addition, pedestrians with mobility limitations may require longer crossing durations and improved infrastructure support. Observational and questionnaire-based studies further reveal that high pedestrian density and prolonged waiting times tend to reduce perceived comfort and satisfaction at intersections, particularly during peak traffic periods [8].

Overall, pedestrian LOS is influenced by a combination of operational conditions, safety considerations, and infrastructure characteristics. Important factors include signal waiting time, pedestrian crowding levels, vehicle speed, conflicts with turning vehicles, and the design of crossing facilities. In contrast to traditional motorist-focused evaluations, pedestrian-oriented studies place stronger emphasis on perceived safety, walking comfort, and accessibility when evaluating service quality at signalized intersections, highlighting the importance of designing intersections that support safe and convenient pedestrian movement [15]. Moreover, the provision of pedestrian facilities such as refuge islands, visible pavement markings, adequate lighting, and properly timed pedestrian signals can substantially enhance the walking experience at intersections. Effective intersection design and traffic management strategies can therefore improve pedestrian safety and comfort while reducing potential conflicts with vehicular traffic.

Table 3. Pedestrian-Specific Influencing Factors Identified in Perceived LOS Studies

Sl. No.	Influencing Factor	Description	Category	Frequency in Literature	Impact on Perceived LOS
1	Waiting Time	Time spent waiting for pedestrian green signal	Operational	Very High	Strong negative impact when increased
2	Crossing Time	Time required to complete crossing	Operational	High	Longer crossing time reduces comfort
3	Pedestrian Density	Number of pedestrians per unit area	Comfort	Very High	High density reduces perceived space and comfort
4	Vehicle Speed	Speed of approaching vehicles	Safety	High	Higher speeds increase perceived risk
5	Turning Conflicts	Conflicts with turning vehicles during crossing	Safety	Very High	Strong negative impact on safety perception
6	Heavy Vehicle Presence	Proportion of buses/trucks	Safety	High	Increases fear and perceived danger
7	Signal Visibility	Clarity and visibility of pedestrian signals	Control / Safety	High	Poor visibility reduces confidence
8	Crossing Length	Width of road to be crossed	Geometric	Moderate–High	Longer crossings increase exposure risk
9	Footpath Width	Effective walking width on approach	Comfort	High	Narrow width reduces comfort
10	Buffer Space	Separation between pedestrians and traffic	Safety	Moderate	Lack of buffer reduces safety perception
11	Obstructions	Encroachments or physical barriers	Comfort	Moderate	Obstructions reduce walking convenience

2.4 Common Factors Influencing Perceived Level of Service

A combined review of motorist-focused and pedestrian-focused studies indicates that several influencing variables repeatedly appear across both categories of road users. Although the level of importance assigned to these variables may differ, the fundamental determinants of perceived Level of Service display considerable similarity. Waiting time (or control delay) is the variable most frequently reported as influencing perceived service quality. Both motorists and pedestrians relate extended waiting periods with dissatisfaction, frustration, and reduced travel efficiency. Within pedestrian research, waiting time is often closely associated with perceived safety and exposure to traffic risk, whereas in motorist studies it is linked with operational inefficiency and limitations in manoeuvrability.

The presence of heavy vehicles is another commonly reported factor across several studies. For motorists, a greater proportion of buses and trucks reduces manoeuvrability and increases discomfort due to restricted visibility and inconsistent speed patterns. For pedestrians, heavy vehicles raise perceived danger during crossing because of their size, wider turning radius, and longer stopping distance. In a similar way, turning conflicts and vehicle speed have substantial influence on both user groups. Motorists tend to view turning congestion and unpredictable pedestrian crossings as causes of delay and driving stress, while pedestrians often interpret turning vehicles and higher speeds as serious safety threats. Traffic volume, signal visibility, and overall intersection geometry also contribute to perceived service quality for both groups of users.Although most previous studies have examined these factors separately for different user groups, they clearly indicate a strong level of interdependence. Waiting time experienced by one group frequently results from signal priority provided to the other group. The movement of heavy vehicles can simultaneously influence both safety and comfort levels.

Table 4. Common Factors Influencing Perceived LOS Studies

Common Influencing Factor	Evidence in Motorist Studies	Evidence in Pedestrian Studies	Nature of Influence
Waiting Time / Control Delay	Strong	Strong	Direct negative effect when increased
Heavy Vehicle Presence	Strong	Strong	Reduces comfort and safety
Turning Conflicts	Moderate–High	High	Increases stress and perceived risk
Traffic Volume	Strong	Moderate	Raises congestion and exposure
Vehicle Speed	Moderate	Strong	Increases perceived danger
Signal Visibility	Moderate	High	Affects confidence and compliance
Intersection Geometry	Moderate	Moderate	Influences manoeuvrability and exposure
Safety Perception	Moderate	Very Strong	Central to pedestrian satisfaction

III. Modelling Approaches in Perceived LOS Studies

Perception-based Level of Service (LOS) modelling has been examined using multiple analytical methods, ranging from conventional statistical procedures to more advanced data-driven techniques. The selection of a modelling approach typically depends on the characteristics of the data, the structure of the dependent variable, and the requirement to represent nonlinear or interaction relationships. Over time, research has gradually moved from basic regression-based models toward classification,

clustering, and machine-learning methods, although most existing studies still concentrate on separate user groups rather than integrated system-level models.

Initial studies frequently applied linear regression to establish relationships between operational variables and perceived service quality. For instance, pedestrian LOS perception has been analysed using factors such as waiting time, pedestrian density, and safety perception, while motorist-perceived LOS has been evaluated using parameters including delay and traffic composition [10], [12]. Although regression techniques are relatively simple to interpret, they often fail to adequately represent complex relationships among variables.

Since perceived LOS ratings are generally ordinal in form, several researchers have employed ordered logit or probit models. These approaches are appropriate for analysing categorical satisfaction levels and have been used in both motorist and pedestrian perception studies [4], [6]. However, these models still depend on predefined parametric assumptions.

To represent behavioural variability among users, researchers have also applied clustering and latent class methods, which categorize users according to similar perception patterns and reveal demographic differences among pedestrian groups [14]. Although useful for identifying perception diversity, these approaches do not directly produce a unified LOS indicator.
Other analytical methods include structural equation modelling (SEM), which enables the incorporation of latent constructs such as comfort and safety perception into LOS evaluation [9]. Simulation-based studies have also been conducted to investigate the influence of operational variables such as queue length and signal cycle duration on perceived service quality [7].

In recent years, machine learning techniques, including artificial neural networks, have been explored to represent nonlinear relationships and complex interactions among variables. These approaches show strong potential for integrating pedestrian and motorist factors within a single predictive framework, although their use in perceived LOS modelling remains relatively limited.

Table 5. Modeling Approaches Used in Perceived LOS Literature

Modelling Approach	Key Researchers	Application (User Group)	Strength	Limitation
Linear Regression	Othayoth & Rao (2017); Marisamynathan & Vedagiri (2019)	Motorist, Pedestrian	Simple and interpretable	Assumes linearity
Ordered Logit / Probit	Chandra & Kumar (2018); Gupta & Velmurugan (2019)	Motorist, Pedestrian	Suitable for ordinal data	Limited nonlinear handling
Multinomial Logistic Regression	Gupta & Velmurugan (2019)	Pedestrian	Handles categorical outcomes	Ignores complex interaction
Clustering / Latent Class	Rahul & Manoj (2020)	Pedestrian	Captures heterogeneity	No unified LOS index
Structural Equation Modelling (SEM)	Maitra & Sarkar (2021)	Motorist	Models' latent variables	Complex calibration
Simulation-Based Models	Kar et al. (2019)	Motorist	Scenario testing	Limited subjective modelling
Machine Learning / ANN	Emerging studies	Both (limited integration)	Captures nonlinear interactions	Requires large datasets

IV. Research Gaps

Existing research indicates notable progress in perception-based Level of Service (LOS) evaluation for both motorists and pedestrians. Nevertheless, several shortcomings continue to exist. First, most investigations assess motorists and pedestrians independently. Motorist-related models primarily consider operational elements such as delay, queue length, and traffic composition, whereas pedestrian-focused models emphasize waiting time, perceived safety, density, and comfort. Although both groups share a number of influencing variables, they are generally analysed within separate analytical frameworks.

Second, interaction effects between different user groups are seldom incorporated in modelling. Signalized intersections function as shared environments in which pedestrian crossings affect vehicle movement and traffic flow influences pedestrian waiting time and perceived safety. Despite this mutual dependence, many existing studies treat these interactions as secondary factors rather than primary determinants of service quality.

Third, methodological constraints limit the possibility of integration. Numerous studies depend on regression or ordinal modelling approaches that frequently assume linear relationships and therefore cannot fully represent complex interaction dynamics. Although clustering and structural equation modelling techniques have been used to capture user heterogeneity, these approaches remain focused on individual user categories rather than system-level analysis.Overall, current literature lacks a comprehensive framework that evaluates intersection performance from a unified user-perception perspective.

V. DISCUSSION

The literature suggests a gradual shift from strictly operational LOS evaluation toward perception-oriented assessment frameworks. Studies centred on motorists highlight the influence of variables such as delay, traffic composition, and signal

coordination, whereas pedestrian-related research stresses factors including waiting time, vehicle speed, pedestrian density, and turning conflicts.

Although several common determinants have been identified, the two research streams remain mostly separate. Signalized intersections operate as shared interaction spaces, and the service quality experienced by one user group frequently influences the other. For example, longer pedestrian green phases may improve pedestrian satisfaction but simultaneously increase vehicle delay. Such trade-offs are seldom examined within a single evaluation framework.

Methodological limitations further restrict current research efforts. Many studies rely on regression-based methods that may not fully capture nonlinear relationships present in heterogeneous traffic conditions. Even though advanced techniques such as clustering, structural equation modelling, and machine learning demonstrate potential, their use in integrated perceived LOS modelling is still limited.

VI. CONCLUSION

This review investigated perception-based Level of Service (LOS) evaluation at signalized intersections operating under heterogeneous traffic conditions. Existing research demonstrates a clear transition from traditional operational delay-based evaluation toward user-oriented perception frameworks. Motorist-focused studies typically emphasize delay, traffic composition, and operational efficiency, whereas pedestrian research highlights waiting time, safety perception, and walking comfort.

However, the literature identifies an important limitation: pedestrian and motorist LOS models are generally developed independently, even though strong interaction exists between these user groups at signalized intersections. This separation restricts a comprehensive evaluation of intersection performance and ignores potential trade-offs between mobility and safety.

Moreover, most perception-based studies depend on regression or ordinal modelling approaches that may not adequately capture complex behavioral interactions. Establishing a unified perception-based LOS framework that integrates both pedestrian and motorist perspectives would provide a more realistic representation of intersection performance in heterogeneous traffic environments. Such an approach could contribute to more balanced and user-oriented urban transportation planning.

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