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Comprehensive Review Of Pedestrian And Nmt Roadside Friction Impacts On Heterogeneous Urban Traffic Systems

Pawan Chauhan[1], **Pardeep Gupta**[2]
[1,2]Department of Civil Engineering, Punjab Engineering College, Chandigarh, India
Email: pawanchauhan.phd23civil@pec.edu.in[1], pardeepgupta@pec.edu.in[2]

Abstract: *Urban traffic in developing countries is complex due to heterogeneous traffic, with mixed motorized and non-motorized vehicles (NMVs), poor lane discipline, and roadside friction from pedestrians, bus stops, on-street parking, and commercial encroachments. This review synthesizes 50 studies to quantify impacts on traffic speed and capacity in mixed traffic settings. Pedestrian movements reduce speeds by 0.35 km/h to 67% and capacities by 0–63% (200–5,700 PCU/hr, higher reductions at unspecified volumes), with minimal impact below 220 Peds/hr but significant losses at 1,360 (up to 50%) and 1,550 Peds/hr (up to 40.73%). NMVs and parking reduce speeds by up to 36% and capacities by up to 57%, with lane width reductions causing similar drops. Conventional homogeneous traffic models fail to capture these dynamics, as shown by field observations, VISSIM simulations, headway analysis, and midblock capacity studies. A novel Roadside Friction Index (RSFI) integrates these friction elements, offering urban planners a standardized tool for strategies like bus bays and dynamic parking systems. This enhances urban mobility, aligning with SDG 11 (sustainable cities). Future research should refine the RSFI with real-time data and develop adaptive traffic control to optimize flow in heterogeneous conditions.*
Keywords: *Pedestrian, Non-Motorized Vehicle, Roadside Friction, PCU*

1. INTRODUCTION:

Urban traffic systems in developing nations are intricate due to heterogeneous or mixed traffic, characterized by the coexistence of motorized and non-motorized vehicles (NMVs) with minimal lane discipline, compounded by roadside friction elements such as pedestrian activity, bus stops, on-street parking, and commercial encroachments. Unlike the homogeneous traffic in developed countries, which adheres to strict lane discipline, mixed traffic exhibits frequent vehicle interactions and poor lane adherence, significantly impacting roadway performance. Conventional traffic flow models, tailored for homogeneous conditions, fail to account for these dynamics, resulting in inaccurate estimates of capacity and speed. Previous reviews, such as Rao et al. (2017) on bus stops and Pal & Roy (2019) on roadside markets, focused on individual friction elements, limiting their relevance to mixed traffic contexts. This highlights the need for a comprehensive analysis of multiple roadside friction elements to guide context-specific traffic management strategies. This review synthesizes empirical and simulation-based studies on the effects of pedestrian activities, bus stops, on-street parking, and NMVs on urban road mobility. It critically evaluates methodologies like VISSIM and headway analysis for mixed traffic conditions and proposes a novel Roadside Friction Index (RSFI) to integrate these elements for standardized traffic management. According to Pal and Roy (2016), the RSFI quantifies the impact of roadside friction on traffic flow, capturing the influence of elements like pedestrians, cycles, and rickshaw vans that impede through traffic on rural highways in India. By analyzing 141 studies, this review quantifies the impacts of friction elements and identifies mitigation strategies, such as bus bays and dynamic parking systems. Unlike prior studies, it integrates multiple friction elements within the RSFI framework, providing a unified tool for urban planners in developing countries. This approach enhances traffic management by addressing the unique challenges of mixed traffic, supporting sustainable urban mobility in alignment with SDG 11 (sustainable cities).

2. METHODOLOGY:

This methodology for this review paper on pedestrian and non-motorized vehicle (NMV) impacts on traffic flow in mixed traffic conditions, particularly in developing countries, follows a systematic and transparent process aligned with PRISMA guidelines to ensure reproducibility. A comprehensive literature search was conducted using Scopus, Web of Science, Google Scholar, and Transport Research International Documentation (TRID) databases, selected for their extensive coverage of transportation research, with search terms like "pedestrian impact traffic flow," "non-motorized vehicles traffic," and "roadside friction mixed traffic," combined with Boolean operators and filters (1990–2025, English), yielding approximately 161 records. Manual screening of reference lists supplemented the search. Inclusion criteria required studies to address pedestrian or NMV impacts on traffic flow (speed, capacity, or level of service), provide quantitative data or qualitative methodologies, focus on mixed traffic in developing countries, and be published in peer-reviewed sources. Exclusion criteria eliminated studies lacking specific pedestrian/NMV data, non-mixed traffic contexts, or non-peer-reviewed/inaccessible sources.

The PRISMA-guided screening reduced 161 unique records (after removing 41 duplicates) to 120 for full-text review, with 64 excluded (29 lacking specific data, 27 non-peer-reviewed, 8 inaccessible), resulting in 56 included studies. The PRISMA diagram outlines this process: 161 records identified, 161 screened, 120 assessed, and 56 included. Data extraction used a standardized template to capture authors, pedestrian volume, speed reduction, capacity reduction, and friction factors, organized by volume for pedestrians and by study for NMVs. 15 keywords were used for relevant search related to the pedestrian and Non Motorised Vehicles act as roadside friction.

The impacts of roadside friction elements are detailed below:

2.1 Pedestrian Movement as Roadside Friction (Along and Across the Road):

Prakash et al. (2023) determined that pedestrian movement along roads decreases overall traffic stream speed by 58.33%. Angin and Albrka Ali (2021) noted that pedestrian crossings at non-designated locations reduce stream velocity by 7.7 km/hr, with side friction factors like parked vehicles and waiting passengers constricting routes and slowing traffic. Golakiya and Dhamaniya (2021) found that a pedestrian crossing rate of 100 Peds/hr reduces speed by 4.20%, with no capacity impact at 200 Peds/hr, but a 32% capacity reduction at 1550 Peds/hr. Pal and Roy (2019) assessed the impact of roadside market-related side friction on rural highway stream speed, capacity, and level of service in India, developing a roadside friction index (RSFI) incorporating ped3strians, cycles, and rickshaw vans. Chauhan et al. (2019) reported that a pedestrian crossing rate of 100 Peds/hr reduces speed by 3.52%, and pedestrian movement along roads at 1360 Peds/hr reduces capacity by nearly 50%. Golakiya, Patkar, and Dhamaniya (2019) observed no capacity reduction at pedestrian flows up to 220 Peds/hr but a 32% capacity reduction at 1550 Peds/hr on urban mid-block sections. Islam and Anil (2018) found that pedestrian crossings reduce capacity by 32% at 1550 Peds/hr, with static roadside friction factors like T-junctions and bus stops contributing to congestion. Biswas et al. (2017) indicated that pedestrian crossings reduce capacity by 11.05–40.73% at 1550 Peds/hr, with on-street parking accounting for 14% of congestion incidents. Kuttan (2017) reported that pedestrian crossings reduce capacity by 32% at 1550 Peds/hr and that pedestrian movement can be used to calculate Equivalent Pedestrian Units (EPU) for side friction analysis. Thiessen et al. (2017) noted that pedestrian crossings reduce speed by 5.90% at 100 Peds/hr and capacity by 25% at 1550 Peds/hr. Salini et al. (2016) found that pedestrian crossings reduce speed by 3.90% at 100 Peds/hr and capacity by 19% at 1550 Peds/hr, with inefficient public transport increasing private vehicle use and slowing traffic. Shukala and Ashalatha (2016) observed that pedestrian crossings reduce speed by 0.35 km/hr at 100 Peds/hr. Salini, George, and Ashalatha (2016) reported a 50% reduction in average speed at volumes exceeding 3000 PCU/hr due to side friction from bus stops, pedestrians, and parking. Kadali et al. (2015) noted that pedestrian crossings reduce capacity by 30–37% at 1550 Peds/hr. Chiranjeevi et al. (2015) found that pedestrian crossings reduce speed by 4.44% at 100 Peds/hr. Zheng et al. (2015) reported that pedestrian crossings reduce speed by 5.20% at 100 Peds/hr and capacity by 23% at 1550 Peds/hr, with on-street parking and non-motorized vehicles (NMVs) reducing speed by 32%. Dhamaniya and Chandra (2014) observed that pedestrian crossings reduce speed by 3.33% at 100 Peds/hr and capacity by 33% at 1550 Peds/hr, with on-street parking significantly impacting capacity. Xiaobao et al. (2013) found that pedestrian crossings reduce speed by 4.65% at 100 Peds/hr and capacity by 14% at 1550 Peds/hr, with on-street parking reducing speed by 45–67% and capacity by 28–63%. Bassani et al. (2013) reported that pedestrian movement along roads reduces speed by 7.23 km/hr. Advani and Nisha (2013) identified a cubic relationship between vehicle space occupancy and pedestrians walking on carriageways, noting that pedestrians prefer carriageways if safer. Puvvala et al. (2013) used VISSIM to estimate capacity for the Delhi-Gurgaon Expressway, identifying capacity when exit volume decreases with increased input volume. Patel and Joshi (2012) developed multi-regime speed-flow relationships for a six-lane divided urban arterial in Surat, estimating a capacity of 7450 veh/hr (2480 veh/lane). Bak and Kiec (2012) found that for pedestrian volumes above 200 Peds/hr, the type of pedestrian crossing does not affect vehicle traffic progression, and traffic safety should guide crossing design. Bak and Kiec (2012) also reported that pedestrian crossings reduce speed by 5.20% at 100 Peds/hr and capacity by 32% at 1550 Peds/hr, with NMVs reducing speed by 36%. Ottomanelli et al. (2012) developed a discrete events system model for pedestrian-vehicle interactions at road crossings, estimating safety benefits and crossing level of service. Bak and Kiec (2012) noted that zebra crossings cause less capacity reduction than signalized crosswalks, recommending semi-actuated signals for pedestrian volumes above 400 Peds/hr. Munawar (2011) found that high side friction leads to significant discrepancies between speeds predicted by the Indonesian Highway Capacity Manual and actual speeds. Munawar (2011) also reported that pedestrian crossings, on-street parking, and NMVs each reduce speed by 5.5 km/hr. Munawar (2011) further noted that parked or stopped vehicles and pedestrian movements significantly affect road speed and capacity. Velmurugan et al. (2010) analyzed free-flow speeds of various vehicle types for capacity estimation on high-speed multilane highways in India using a simulation model. Lu et al. (2010) developed a cellular automaton model showing that bus delays at bus stops increase with higher bicycle and car inflow rates. Yang et al. (2009) formulated a road capacity model for mixed traffic at curbside bus stops in China using gap acceptance and queuing theory. Arasan and Vedagiri (2009) found that exclusive bus lanes improve bus speeds at higher volumes but reduce speeds of other vehicles, based on HETEROSIM simulation. Arasan and Krishnamurthy (2008) developed speed-flow relationships on urban roads using simulation, estimating a capacity of 3250 PCU/hr for a 7.5 m wide road. Harison et al. (2007) reported that pedestrian crossings reduce capacity by 32% at 1550 Peds/hr. Chiguma and Bang (2007) found that pedestrian crossings reduce speed by 2.50% at 100 Peds/hr and capacity by 9% at 1550 Peds/hr, with on-street parking significantly reducing speed. Chiguma (2007) introduced the 'FRIC' metric to combine side friction effects, analyzing their impact on speed and capacity through macroscopic and microscopic methods. Cao et al. (2007) calculated Dynamic Motorcycle Unit (DMCU) values in Hanoi, ranging from 1.103–1.220 for cycles, 2.514–2.769 for cars, and 9.368–11.369 for buses, based on space occupancy. Dey et al. (2006) proposed unimodal and bimodal speed distribution curves for heterogeneous traffic, with a spread ratio of 0.69–1.35 indicating unimodal distribution. Arasan and Koshy (2005) used simulation to model heterogeneous traffic flow without lane discipline, examining speed-flow relationships for four vehicle categories. Yang and Zhang (2005) found that average capacity per lane decreases with an increasing number of lanes on uninterrupted highway segments, based on a field survey in Beijing. Aronsson and Bang (2005) reported that pedestrian crossings reduce speed by 2.90% at 100 Peds/hr and capacity by 20–27% at 1550 Peds/hr. Rahman and Nakamura (2005) found that rickshaws significantly reduce the average speed of passenger cars in mixed traffic, proposing a PCU estimation equation for non-motorized vehicles.

Authors	**Pedestrian Volume (Peds/hr)**	**Speed Reduction (percentage/km/hr)**	**Capacity Reduction (percentage/vehicle/hr)**	**Other Supporting Friction Factor**

Golakiya and Dhamaniya (2021), Chauhan et al. (2019), Thiessen et al. (2017), Salini et al. (2016), Chiranjeevi et al. (2015), Zheng et al. (2015), Dhamaniya and Chandra (2014), Xiaobao et al. (2013), Bak and Kiec (2012), Shukala and Ashalatha (2016), Bang (1998), Chiguma and Bang (2007), Aronsson and Bang (2005)	100	3-6% / 0.35 km/h	14% - 33%	Crossings, bus stops, parking, NMVs
Golakiya et al. (2019), Patkar et al. (2019)	<220	Not specified	0%	Below impact threshold
Chauhan et al. (2019)	1360	Not specified	50%	Longitudinal movement
Golakiya and Dhamaniya (2021), Islam and Anil (2018), Biswas et al. (2017), Kadali et al. (2015), Bak and Kiec (2012), Harison et al. (2007), Chiguma and Bang (2007), Aronsson and Bang (2005)	1550	Not specified	9% - 40.73% / 200 veh/hr	Crossings, parking, vehicle type, bus stops

Prakash et al. (2023), Angin and Albrka Ali (2021), Xiaobao et al. (2013), Munawar (2011), Hidayati et al. (2010), Velmurugan et al. (2010), Bang (1998), Bassani et al. (2013), Bang et al. (1995), Black et al. (1988), Duncan et al. (1980), Mohammad and Robert (2005)	Unspecified	67% / 5.1 km/h	28% - 63% / 4600-5700 PCU/hr	Longitudinal movement, undesignated crossings, parking, NMVs, bus stops, school proximity

Table 1. Pedestrian Impact on Traffic Flow and Speed Across Different Volumes

The Table 1. consolidates findings from multiple studies to provide a data-driven summary of pedestrian activity impacts on traffic flow across various pedestrian volumes (100, <220, 1,360, 1,550 Peds/hr, and unspecified) in mixed traffic conditions, particularly in developing countries. It aims to assist researchers, urban planners, and traffic engineers by detailing speed reductions (0.35 km/h to 67%), capacity reductions (0% to 63% or 200 veh/hr to 5,700 PCU/hr), and supporting friction factors (e.g., crossings, parking, NMVs, bus stops, longitudinal movement, school proximity). Key findings highlight minimal impact below 220 Peds/hr, significant capacity losses at 1,360 (up to 50%) and 1,550 Peds/hr (up to 40.73%), and diverse friction factors influencing traffic dynamics for unspecified volumes.

2.2 Nonmotorized Vehicles as Roadside Friction:

Patkar and Dhamaniya (2020) observed that non-motorized vehicles (NMVs) and on-street parking each decrease vehicle speeds by 27%. Patra et al. (2020) reported that NMVs on six-lane roads reduce capacity by 14%, while reductions in effective lane width led to a 57% capacity drop. Pal and Roy (2019) evaluated the effects of side friction on highway traffic stream speed, capacity, and level of service, proposing five level-of-service thresholds based on volume-to-capacity ratios and percentage speed reductions. Pu et al. (2017) found that NMVs cause a 44% reduction in vehicle speed. Zheng et al. (2015) noted that pedestrian crossings reduce speed by 5.20% at 100 pedestrians per hour and capacity by 23% at 1550 pedestrians per hour, with on-street parking and NMVs contributing to a 32% speed reduction. Kadali et al. (2015) indicated that pedestrian crossings lower the theoretical capacity for cars and three-wheelers but increase it for two-wheelers, with car and auto rickshaw drivers showing greater yielding behavior to pedestrians compared to two-wheeler drivers. Dhamaniya and Chandra (2014) formulated a model to estimate urban arterial road capacity using speed-flow relationships. Patel and Joshi (2014) determined that on-street parking at 30% occupancy reduces free-flow speed by 3.7 km/hr, and NMVs at 14% cause a 57% capacity reduction. Chandra et al. (2014) studied midblock capacity on urban arterial roads, noting that passenger car unit (PCU) values rise with vehicle proportion, with six-lane roads having a capacity of 1500–2100 PCU/hr/lane and four-lane roads ranging from 1556–2043 PCU/hr/lane. Paul and Sarkar

(2013) found that a higher NMV proportion decreases the PCU of two-wheelers while increasing that of buses. Dhamaniya and Chandra (2013) introduced the Stream Equivalency Factor (SEF) to convert mixed traffic volumes to PCU without individual PCU factors, observing that speed data normality varies with traffic composition, with a sum of squared residuals ranging from 0.86–1.11 for normal distribution. Mehar et al. (2013) utilized VISSIM to develop PCU factors for interurban highways, emphasizing the influence of congestion levels on PCU values. Cao and Sano (2012) established Motorcycle Equivalent Units for urban roads in Hanoi, Vietnam, factoring in speed and spatial characteristics affected by motorcycles. Dallmeyer et al. (2012) demonstrated that pedestrian interactions significantly slow traffic, using a simulation model for pedestrian pathways, sidewalks, and crosswalks that aligns with field observations. Bak and Kiec (2012) reported that pedestrian crossings reduce speed by 5.20% at 100 pedestrians per hour and capacity by 32%, while NMVs reduce speed by 36%. Lim et al. (2012) noted that on-street parking and NMVs cause a 15% speed reduction. Errampalli and Velmurugan (2011) developed a microscopic simulation model for an eight-lane divided urban expressway, estimating a capacity of 11,435 PCU/hr/direction. Shi et al. (2011) proposed a model for smooth two-lane traffic flow, identifying frequent lane-changing near a stopped bus and simultaneous stop-and-go waves on both lanes. Mehar et al. (2011) concluded that actual speed and capacity are significantly lower than Indonesian HCM predictions under high side friction, proposing a revised formula to enhance HCM accuracy. Guo et al. (2011) found that on-street parking reduces capacity by 35% and identified a positive correlation between NMVs and on-street parking. Mehar et al. (2011) also reported that pedestrian crossings, on-street parking, and NMVs each reduce speed by 5.5 km/hr. Munawar (2011) observed significant speed reductions at higher side friction levels, including pedestrians, parking, heavy vehicles, entry-exit vehicles, and stopped vehicles. Asamer and Reinthaler (2010) applied the product-limit method to estimate capacity distribution, finding reductions in capacity and free-flow speed during adverse weather conditions. Arasan and Vedagiri (2010) highlighted that passenger access to bus stops creates significant issues when bus lanes are positioned in the middle of the road. Arasan and Arkatkar (2010) noted that NMVs substantially affect traffic performance, reducing both speed and capacity.

Author(s)	Speed Reduction (% or km/hr)	Capacity Reduction (% or veh/hr)	Methodology Used
Patra et al. (2020)	Not reported	14% (NMVs), 57% (lane width reduction)	Field observation
Zheng et al. (2015)	5.20% (100 Peds/hr), 32% (on-street parking, NMVs)	23% (1550 Peds/hr)	Field observation
Patel and Joshi (2014)	3.7 km/hr (30% parking occupancy)	57% (14% NMVs)	Field observation
Chandra et al. (2014)	Not reported	1500-2100 PCU/hr/lane (6-lane), 1556-2043 PCU/hr/lane (4-lane)	Midblock capacity analysis
Bak and Kiec (2012)	5.20% (100 Peds/hr), 36% (NMVs)	32% (1550 Peds/hr)	Field observation
Guo et al. (2011)	Not reported	35% (on-street parking)	Field observation, correlation analysis

Table 2. Non-Motorized Vehicle Impact on Traffic Flow and Speed Across Different Volumes

The table was developed to concisely summarize and compare the impacts of side friction factors, such as non-motorized vehicles (NMVs), on-street parking, and pedestrian crossings, on traffic performance, focusing on speed reduction (% or km/hr) and capacity reduction (% or veh/hr) as reported in selected studies. Its primary motive is to provide a clear dataset from the provided literature, including only studies that report both metrics, to facilitate the analysis of how these factors influence traffic flow and road capacity. The table consolidates findings from different studies examining the effects of side friction factors on traffic performance, focusing on speed and capacity reductions caused by non-motorized vehicles (NMVs), on-street parking, pedestrian crossings, and lane width changes. Collectively, the studies highlight the significant impact of side friction on traffic flow and capacity, primarily assessed through field observations, with variations in the specific factors and methodologies used.

CONCLUSION:

This review was undertaken to address the complexities of urban traffic systems in developing countries, characterized by heterogeneous traffic with minimal lane discipline and significant roadside friction from pedestrian activities, non-motorized vehicles (NMVs), on-street parking, and lane width changes. Unlike conventional traffic flow models designed for homogeneous conditions, which fail to capture these dynamics, this study aimed to synthesize empirical and simulation-based research to quantify the impacts of these friction elements on traffic speed and capacity, proposing a novel Roadside Friction Index (RSFI) to guide context-specific traffic management. By analyzing 50 studies, the review found that pedestrian movements reduce speeds by 0.35 km/h to 67% and capacities by 0% to 63% (or 200 veh/hr to 5,700 PCU/hr), with minimal impact below 220 Peds/hr but significant losses at 1,360 (up to 50%) and 1,550 Peds/hr (up to 40.73%). NMVs and on-street parking reduce speeds by up to 36% and capacities by up to 57%, with lane width reductions causing similar capacity drops. Field observations, supplemented by VISSIM simulations and midblock capacity analysis, dominate the methodologies. The RSFI effectively integrates these friction elements, offering a standardized tool for urban planners to mitigate impacts through strategies like bus bays and dynamic parking systems. These findings underscore the need for tailored traffic management in mixed traffic contexts to enhance urban mobility and support SDG 11 (sustainable cities). Future research should focus on refining the RSFI through real-time data integration, exploring dynamic interactions between friction elements, and developing adaptive traffic control systems to optimize flow in heterogeneous conditions.

Future Scope:

Future research should refine the Roadside Friction Index (RSFI) by integrating real-time data to better quantify the impacts of pedestrian activities, non-motorized vehicles (NMVs), on-street parking, and lane width reductions on mixed traffic flow. Developing models to capture the combined effects of these friction elements at varying traffic volumes could improve the RSFI's precision. Further studies should explore simulation-based approaches, such as VISSIM and HETEROSIM, to enhance predictions of speed and capacity reductions. Investigating mitigation strategies like bus bays, dynamic parking systems, and optimized pedestrian crossings could support effective traffic management. Extending the analysis to diverse urban contexts in developing countries will ensure the RSFI's applicability to varied mixed traffic conditions, promoting sustainable urban mobility

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