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Traffic Volume Study and Intersection Capacity Analysis of Selected Junctions on NH 169A, Udupi–Shivamogga Corridor

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ABSTRACT

Rapid growth in vehicle ownership and tourist movement has made National Highway 169A, which links Udupi to Shivamogga through the coastal and Malenadu regions of Karnataka, increasingly congested and accident-prone. This study investigates two unsignalized T-intersections on this corridor, Athrady and Hiriyadka, with the aim of quantifying prevailing traffic conditions and recommending engineering measures to improve safety and efficiency. Classified traffic-volume counts were carried out manually over two consecutive days at each intersection, covering the morning (08:00-10:00) and evening (16:00-18:00) peak windows, and vehicle counts were converted to Passenger Car Units using Indian Roads Congress conversion factors. Speed and delay characteristics were measured on three connecting stretches using the floating-car method, and a road-inventory survey covering twenty-eight geometric, signage, marking and safety parameters was conducted along the six-kilometre study stretch. Intersection capacity was estimated using the Indian Roads Congress weaving-section formula for rotary design, and signal timings were computed by Webster's method. Results show a critical peak-hour flow of 1,498 PCU/h at Athrady (09:00-10:00) and 868 PCU/h at Hiriyadka (17:00-18:00), with two-wheelers and passenger cars together contributing more than three-quarters of the flow at both locations. Running speeds along the corridor ranged between about 44 and 81 km/h. The inventory survey found an absence of street lighting, crash barriers, guideposts and marked pedestrian crossings along most of the stretch. Weaving-section analysis gave rotary capacities of 2,056 veh/h at Athrady and 2,092 veh/h at Hiriyadka, while Webster's method yielded optimum cycle times of 52 seconds at Athrady and 120 seconds at Hiriyadka. The study concludes that signalisation is practicable at Athrady, whereas the excessive cycle length at Hiriyadka favours a channelised roundabout with improved lighting and signage instead.

Keywords: Traffic volume study, Passenger Car Unit (PCU), Speed and delay study, Intersection capacity, Signal design

INTRODUCTION

Manipal, a university town within Udupi City in coastal Karnataka, and the surrounding stretch of National Highway 169A experience a sustained rise in motor-vehicle traffic driven by student population, tourism and local commerce. National Highway 169A runs from Malpe Harbour in Udupi to Thirthahalli, connecting the Karavali (coastal) region to the Malenadu region across the Western Ghats, and forms the principal link between Udupi and Shivamogga. Although classified as a national highway, several stretches of NH 169A retain a narrow carriageway, and the road climbs the Agumbe ghat section of the Western Ghats, so that geometric constraints inherited from an older, lower-volume alignment now coexist with traffic demand shaped by a much more urbanised corridor. Growth in vehicle registrations in the region has translated directly into higher traffic volumes, more frequent congestion and greater exposure to crash risk, particularly at the numerous unsignalized minor-road junctions along the corridor. This pattern mirrors a wider trend across India's national and state highway network, where rapid motorisation has consistently outpaced the

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incremental widening and signalisation of intersecting minor roads, leaving junction control lagging behind the traffic it is meant to manage; NH 169A is, in that sense, a representative rather than an exceptional case.

An unsignalized T-intersection in mixed traffic is a particularly demanding environment to manage safely. Two-wheelers, autorickshaws, cars and heavy vehicles differ widely in size, speed and manoeuvrability, and in the absence of channelisation or signal control, drivers must negotiate right-of-way largely through informal gap acceptance rather than any prescribed rule. This is compounded where, as at Athrady and Hiriyadka, the junction also functions as a de facto market or bus-stand frontage, so that pedestrians, parked vehicles, roadside vending and loading activity add further friction to through-traffic beyond the turning movements themselves. The consequence is not only elevated crash risk but also a poor level of service during peak periods, since conflicting turning movements at an uncontrolled junction constrain the achievable capacity of every approach simultaneously rather than any one movement in isolation. Addressing this class of problem in a way that is likely to be acted upon – rather than simply diagnosed – requires, first, a reliable quantitative picture of how much traffic uses the junction and in which movements, and second, an engineering treatment, geometric or signal-based, that is sized to that demand rather than assumed from generic design charts or transplanted from a dissimilar site.

Udupi has grown rapidly as a destination for education, pilgrimage and tourism — anchored locally by Manipal Academy of Higher Education, whose student and staff population alone generates a substantial share of daily trip-making on the corridor — and NH 169A carries a correspondingly high and increasing traffic load as a result. Numerous minor roads join this highway without any form of traffic control, creating conflict zones at unsignalized junctions. Two such locations, Athrady and Hiriyadka, combine significant market and bus-stand activity with unregulated turning movements, making them representative sites for a critical traffic-volume study on this corridor.

Prior research offers considerable guidance on how junctions of this kind have been studied and treated elsewhere, spanning intersection-specific safety audits, broader traffic-volume-counting methodology, and signal-timing design procedures. Section II reviews this literature in turn and identifies the gap it leaves for a semi-urban highway corridor such as NH 169A, before Section III describes the study area, Section IV sets out the field methods used here, and Section V presents and discusses the results.

Against this background, the specific objectives of this study are to: (a) conduct a classified traffic-volume study and a speed-and-delay study at the Athrady and Hiriyadka intersections; (b) estimate the vehicular capacity of each intersection under prevailing conditions and propose a suitable geometric treatment; and (c) design a traffic-signal scheme for both intersections, using field-measured turning movements, and assess its feasibility relative to a geometric alternative.

LITERATURE REVIEW

Research relevant to the present study spans four broad strands: safety and operational studies at unsignalized intersections, case studies of traffic-volume-based intersection improvement in India and neighbouring countries, foundational and regional traffic-volume-counting methodology, and signal-design applications of Webster's method. Each is reviewed in turn below, followed by a statement of the gap the present study addresses.

Safety and capacity studies at unsignalized intersections

Traffic-safety literature consistently identifies unsignalized intersections in mixed-traffic conditions as a disproportionate source of conflict and delay. Bonela and Kadali (2022) review the surrogate safety measures – proxies such as post-encroachment time and time-to-collision that do not require waiting for crash data to accumulate – used to audit T-intersections in developing-country traffic conditions, and argue that such measures are well suited to the heterogeneous, largely uncontrolled traffic seen at Indian minor-road junctions. Ahmed et al. (2016) provide complementary field evidence from Malaysia, showing that right-turning-vehicle behaviour at unsignalized junctions – specifically, the gaps drivers judge acceptable when turning across opposing traffic – is strongly influenced by carriageway width and the directional split of approach volumes, both of which vary substantially between the two intersections examined here.

Case studies of traffic-volume-based intersection improvement

A cluster of Indian case studies, at towns of a scale comparable to Athrady and Hiriyadka, illustrates how classified traffic-volume counts have been used as the evidence base for proposing intersection treatments. Konge and Nikam (2022) document congestion-reduction measures at an intersection on the Badlapur–Katai Road; Lal et al. (2016) report a sustainable-improvement case study at an urban intersection in Ettumanoor; Savithramma et al. (2022) analyse variability at isolated intersections in Tumakuru; and Suthar and Deulkar (2021) study a signalized intersection at Delhi Gate circle in Udaipur. Across these studies, Surisetty and Sekhar (2017) and Reddy et al. (2016) demonstrate that classified volume counts converted to Passenger Car Units, combined with signal-timing analysis by Webster's method, form a practicable and reproducible basis for proposing intersection improvements – the same combination of methods adopted in Section IV of the present study.

Foundational and regional traffic-volume-counting studies

Beyond intersection-specific safety studies, a broader body of work establishes traffic-volume counting itself as the foundation for planning and design decisions. Kumar (2012) sets out the data-collection practices, roles and techniques underlying a traffic-volume survey, while Deshpande (2013) documents the scale and classification of India's road-accident problem that motivates such surveys in the first place. Classified volume-count studies comparable in scope to the present work have been reported on urban and semi-urban stretches across India and neighbouring countries, including Visakhapatnam (Sireesha et al., 2019), Panchkula (Ul et al., 2008), Dhaka (Halder et al., 2013) and Faridpur (Mizanur Rahman & Oli, 2016). Gomasta et al. (2015) and Patel and Bhatt (2018) extend this approach by combining volume counts with intersection geometry and signal-phase characteristics at Bhopal and Surat, respectively – an approach closely mirrored in the present study's combination of a volume study, a road-inventory survey and a capacity analysis at each site.

Signal design using Webster's method

On the signal-design side, Jaysawal et al. (2022) apply Webster's method at a school- and market-fronted intersection in Agra that is broadly comparable in character to Athrady and Hiriyadka, while Shokrolah Shirazi et al. (2022) show, across several intersection case studies, that signal plans built from actual turning-movement counts – rather than assumed or generic traffic splits – better match phase timing to real demand than generic designs. This finding reinforces the field-measurement approach adopted for the signal-design component of the present study (Section IV.E), in which turning-movement PCU flows recorded at each intersection, rather than assumed splits, are used directly in Webster's formula.

Research gap and positioning of the present study

Individually, the studies reviewed above address safety auditing, volume-counting methodology, or signal design, each generally in isolation and typically at a single urban intersection. Comparatively few combine a classified volume study, a speed-and-delay study, a systematic road-inventory survey, and both a capacity and a signal-timing analysis within one field investigation of a semi-urban highway corridor. Nor do they typically compare two intersections on the same corridor to show how differing local conditions — here, market frontage and turning-volume balance at Athrady versus Hiriyadka — can lead to different recommended treatments (signalisation at one, a channelised roundabout at the other) even under a common analytical framework. The present study addresses this gap for NH 169A between Udupi and Shivamogga, and its scope is correspondingly broader than any single study cited above, while remaining grounded in the same field-measurement and Webster's-method traditions they establish. Consistent with this literature, the present analysis is also confined to vehicular counts over a limited survey window; Su et al. (2023) note that weather and seasonal factors measurably affect incident-related delay, a limitation discussed further in Section VI.

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Study Area

National Highway 169A (old designation NH 766E) runs from Malpe Harbour in Udupi to Thirthahalli, where it joins NH 169 to complete the Mangaluru–Shivamogga corridor via Gurupura, Moodabidri, Karkala, Sringeri and Koppa. The road provides the principal connection between the Karavali coastal belt and the Malenadu highland region of Karnataka. Several stretches — Malpe to the Karavali by-pass, Manipal to Perdoor, and Someshwara to Agumbe — remain narrow enough that only light and mini-sized commercial vehicles are permitted, and the Malpe–Hebri stretch was under four-lane widening at the time of this study.

Within this corridor, the route from Hiriyadka through Athrady and Manipal to Udupi city carries the bulk of local traffic. Athrady, roughly 3 km from Manipal, is a small market town of about 3,000 residents where the only significant junction concentrates all local commercial activity. Hiriyadka, roughly 10.2 km from Manipal, is a market town of about 17,000 residents serving the surrounding agricultural belt, with its junction located at the town's main bus stand. Both are unsignalized, uncontrolled T-intersections. Figure 1 shows the location of the two study intersections along the highway.

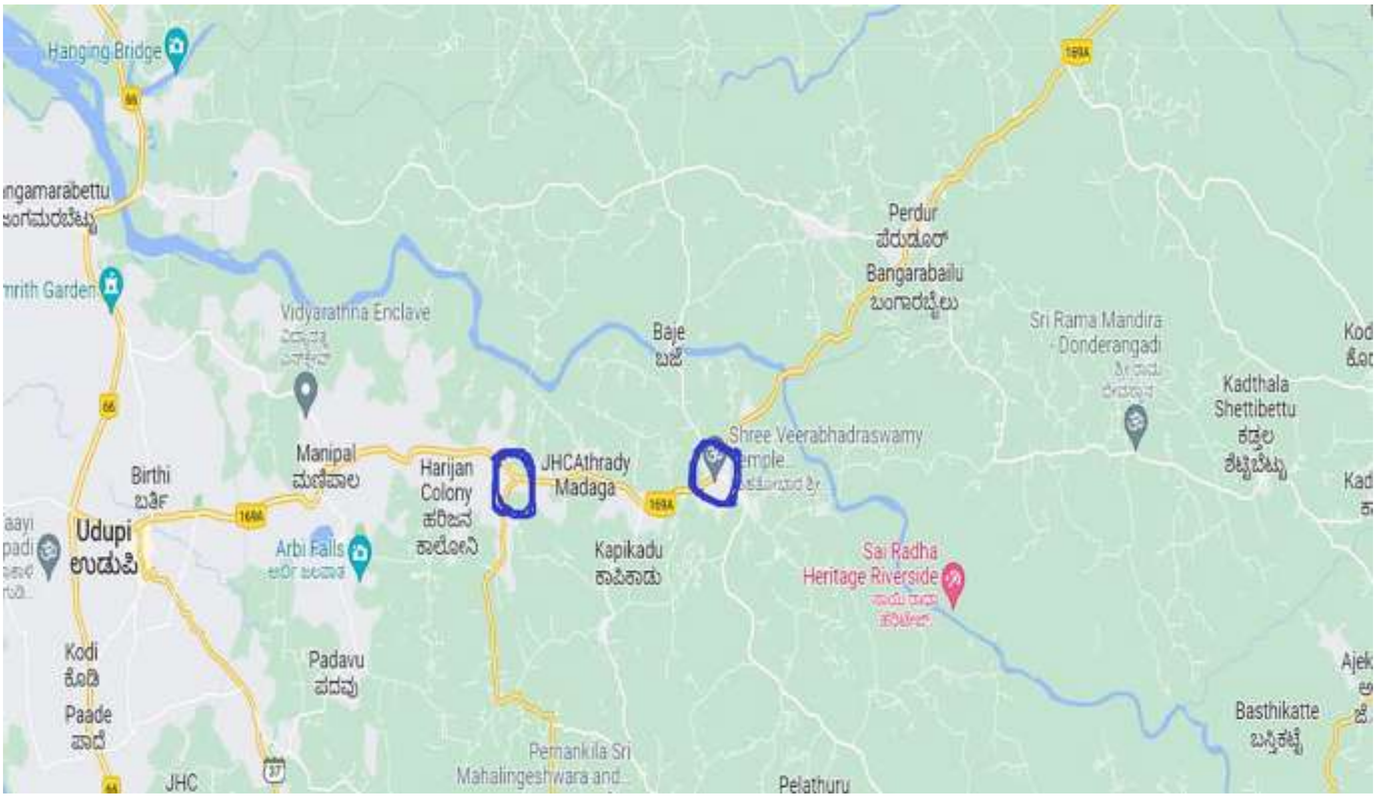

Figure 1. Location of the Athrady and Hiriyadka study intersections along NH 169A (map data © Google)

METHODOLOGY

Traffic volume study

Classified manual volume counts were conducted at each intersection over two consecutive days — 17–18 March 2023 at Athrady and 19–20 March 2023 at Hiriyadka — during the morning (08:00–10:00) and evening (16:00–18:00) peak windows, in 30-minute intervals. Vehicles were classified into four categories (two-wheelers, autorickshaws, passenger cars, and buses/trucks), and each 30-minute count was converted to Passenger Car Units using the conversion factors of IRC 106-1990 (Indian Roads Congress, 1990): 0.75 for two-wheelers, 1.0 for autorickshaws and cars, and 2.8 for buses, trucks and other heavy commercial vehicles. The critical one-hour flow at each intersection was taken as the highest PCU volume obtained by summing any two consecutive 30-minute bins.

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Speed and delay study

Running and journey speeds were measured on three successive stretches of the corridor — IOC to Athrady, Athrady to Ontibettu, and Ontibettu to Hiriyadka — using the floating-car (average-speed) method, with three return trips recorded on each stretch. For each direction, the average traffic volume q was estimated from the number of vehicles overtaking, being overtaken, and travelling in the opposite direction to a test vehicle driven at a speed representative of the stream:

$$q = \frac{(n_a + n_y)}{(t_a + t_w)} \qquad (1)$$

where n_y is the net number of vehicles overtaking the test vehicle in the direction of the stream, n_a is the number of vehicles met from the opposite direction, t_w is the average travel time with the stream, and t_a is the average travel time against the stream. The average journey time was then obtained as

$$t = t_w - \frac{n_y}{q} \qquad (2)$$

from which the average journey speed, and – after subtracting the average stopped delay – the average running speed, were computed for each stretch and direction.

Road inventory survey

A road-inventory survey covering twenty-eight parameters — operating speed, carriageway and shoulder width, drainage, signage, lighting, lane marking, guideposts, curve warnings, pedestrian crossings, crash barriers, pavement condition, parking and bus-stop infrastructure — was carried out along the approximately 6 km stretch between Athrady and Hiriyadka to assess the corridor's adequacy from a road-safety standpoint.

Capacity of the intersections — rotary design

Because both junctions are presently uncontrolled three-legged intersections, their capacity was first evaluated as an equivalent rotary (roundabout) using the IRC weaving-section method. For an assumed entry/exit width of 5 m and a carriageway width of 7.5 m, the weaving width w and weaving length l were computed as

$$w = \frac{(e_1 + e_2)}{2} + 3.5; \quad l = 3w \qquad (3)$$

The proportion of weaving traffic to total traffic, p, was computed for every pair of approaches, and the capacity of the critical weaving section – the pair with the highest p – was obtained from the IRC formula

$$Q_w = \frac{[280w(1 + \frac{e}{w})(1 - \frac{p}{3})]}{(1 + \frac{w}{l})} \qquad (4)$$

Traffic signal design — Webster's method

A three-phase signal scheme, appropriate to a three-legged junction with two conflicting right-turn movements and two non-conflicting through movements, was designed for each intersection using Webster's method. The optimum cycle time C_0 is given by

$$C_0 = \frac{1.5L + 5}{1 - Y} \qquad (5)$$

where $L = 2n + R$ is the total lost time per cycle for n phases and an all-red interval R, and $Y = \Sigma Y_i$ is the sum of the critical flow ratios $Y_i = q_i / S$ for each phase, q_i being the design-hour flow on that phase and S the saturation flow (read from IRC standard values for the corresponding approach width). The effective green time for each phase is then

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$$G_i = \frac{Y_i (C_0 - L)}{Y} \quad (6)$$

RESULTS AND DISCUSSION

Traffic volume and peak-hour flow

Table 1 summarises the critical one-hour PCU volume identified for each of the eight survey sessions, obtained by summing the two consecutive 30-minute bins with the highest combined flow. The highest flow recorded during the study, 1,498 PCU/h, occurred at Athrady between 09:00 and 10:00 on 17 March; the corresponding peak at Hiriyadka was 868 PCU/h, between 17:00 and 18:00 on 19 March (Figure 2). Athrady, being closer to Manipal and the site of continuous roadside market activity, therefore experiences substantially higher peak flow than Hiriyadka even though the two junctions are of comparable geometric size.

Table 1. Critical peak-hour PCU volume by survey session

Intersection	Date (2023)	Session	Critical 1-h Window	Peak Volume (PCU/h)
Athrady	17 Mar	AM	09:00–10:00	**1498**
Athrady	17 Mar	PM	17:00–18:00	814
Athrady	18 Mar	AM	08:30–09:30	1052
Athrady	18 Mar	PM	16:30–17:30	1076
Hiriyadka	19 Mar	AM	09:00–10:00	832
Hiriyadka	19 Mar	PM	17:00–18:00	**868**
Hiriyadka	20 Mar	AM	09:00–10:00	721
Hiriyadka	20 Mar	PM	17:00–18:00	788

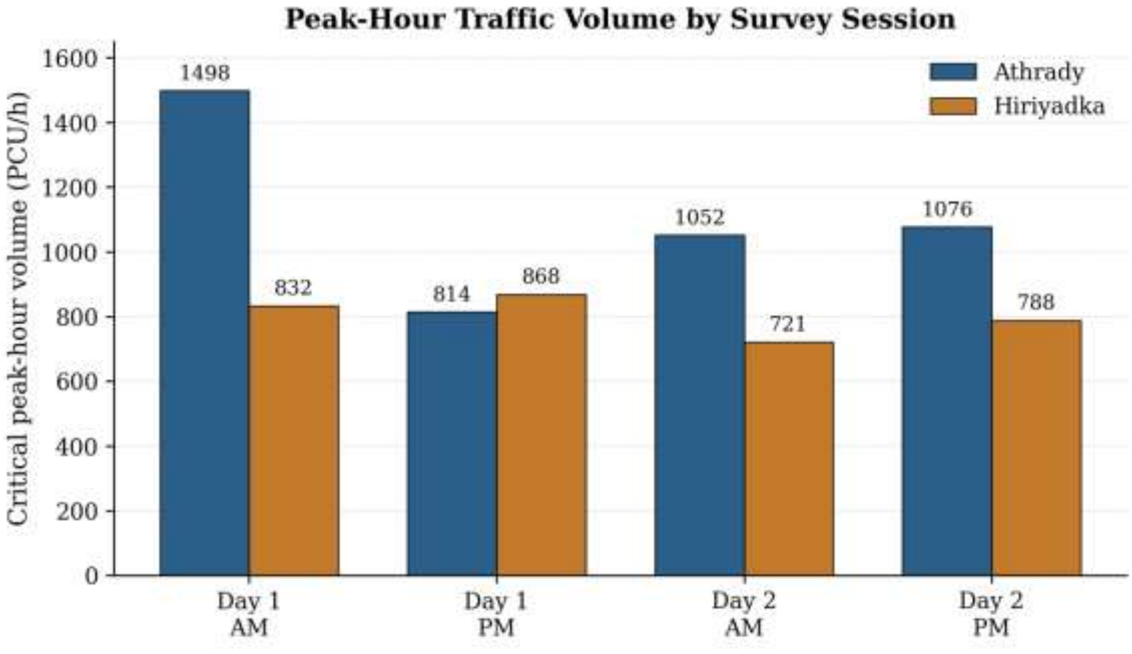

Figure 2. Critical peak-hour traffic volume recorded in each survey session

Figure 2 also shows that the two intersections differ in how consistent their peak-hour flow is from session to session, not only in its average level. At Athrady, the four sessions range from 814 to 1,498 PCU/h, a spread

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of about 62% of the mean session volume (1,110 PCU/h), with the Day 1 morning session standing well above the other three; at Hiriyadka, by contrast, the four sessions range only from 721 to 868 PCU/h, a spread of about 18% of the mean (802 PCU/h). This difference is consistent with the different sources of demand at the two junctions: Athrady's traffic is dominated by continuous roadside market activity, which can produce a pronounced, session-specific surge, whereas Hiriyadka's bus-stand-anchored, more commuter-oriented traffic recurs at a broadly similar level in every session surveyed. The two sites also diverge in their morning-versus-evening balance: at Athrady the Day 1 morning session (1,498 PCU/h) far exceeds the Day 1 evening session (814 PCU/h), while at Hiriyadka the evening session exceeds the morning session on both survey days (868 versus 832 PCU/h on Day 1, and 788 versus 721 PCU/h on Day 2) – a pattern more typical of a location where return trips and evening bus departures outweigh a single dominant morning surge.

The aggregate vehicle composition over the two-day count at each site (Figure 3) shows two-wheelers and passenger cars together accounting for more than three-quarters of the PCU volume at both intersections — about 39% two-wheelers and 38% cars at Athrady, and about 41% two-wheelers and 44% cars at Hiriyadka — with autorickshaws and buses/trucks making up the balance. This heterogeneous, two-wheeler-heavy composition is typical of semi-urban Karnataka highways and has direct implications for junction geometry, since two-wheelers exploit gaps that four-wheeled vehicles cannot, effectively increasing the number of active conflict points at an uncontrolled junction.

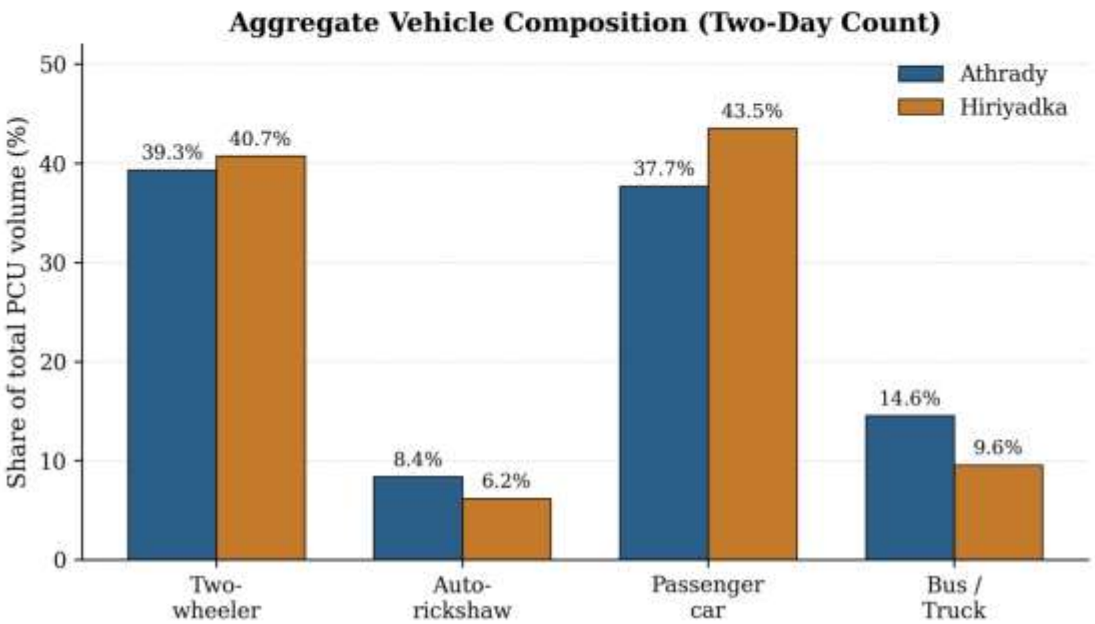

Figure 3. Aggregate vehicle composition by PCU share at Athrady and Hiriyadka

Speed and delay characteristics

Table 2 summarises the average journey and running speeds obtained from the floating-car surveys. Running speeds ranged from about 44 km/h (Athrady to IOC) to 81 km/h (IOC to Athrady), with the IOC–Athrady stretch – the shortest and straightest of the three – showing the highest and most directionally consistent speeds. The Athrady–Ontibettu and Ontibettu–Hiriyadka stretches, which pass directly through the market and bus-stand frontage of the two intersections, show more moderate and more evenly balanced speeds in both directions, consistent with the higher roadside friction and turning activity observed at these locations.

Table 2. Average journey and running speeds (floating-car method)

Road Stretch	Direction	Length (km)	Avg. Journey Speed (km/h)	Avg. Running Speed (km/h)
IOC–Athrady	IOC → Athrady	1	68.90	81.10

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IOC–Athrady	Athrady → IOC	1	40.00	43.79
Athrady–Ontibettu	Athrady → Ontibettu	3	52.78	60.40
Athrady–Ontibettu	Ontibettu → Athrady	3	55.21	65.45
Ontibettu–Hiriyadka	Ontibettu → Hiriyadka	2	52.63	57.69
Ontibettu–Hiriyadka	Hiriyadka → Ontibettu	2	48.58	55.30

Road inventory findings

The road-inventory survey (Table 3) shows that the corridor's principal deficiencies lie in traffic-control hardware and pedestrian provision rather than in pavement condition. Street lighting is absent for almost the entire stretch; no crash barriers, guideposts or curve-warning signs are provided anywhere; pedestrian crossings are unmarked at both intersections; and existing signboards and their support posts are frequently rusted and illegible. A bus bay exists only at Athrady, even though Athrady, Ontibettu and Hiriyadka all have designated bus stops. These findings align with the traffic-volume results: the absence of basic control and delineation measures at exactly the locations carrying the highest and most heterogeneous flow is a direct safety concern.

Table 3. Condensed road-inventory findings, Athrady–Hiriyadka stretch

Parameter	Observed Condition	Recommendation
Operating speed	60 km/h between Athrady and Hiriyadka	Can be raised to 80 km/h where alignment permits
Carriageway / lanes	2-lane, 7.5 m carriageway throughout	Widen where traffic volume warrants
Shoulder width	Approx. 2.36 m	Increase to about 3 m
Street lighting	Absent except a short stretch near Parkala	Provide continuous lighting, especially at both intersections
Signboards & supports	Present, but faded / rusted at many locations	Replace boards; rust-proof supports
Lane / edge / centre-line marking	Present only in parts of the stretch	Provide continuous marking throughout
Guideposts & reflectors	Not provided	Provide at shoulders and curves
Curve warning signs	Not provided	Provide before every curve
Pedestrian (zebra) crossing	Not marked at either intersection	Mark at both Athrady and Hiriyadka junctions
Crash barriers	Not provided anywhere on the stretch	Provide at embankments and sharp curves
Footpath	Present only near Hiriyadka	Extend to Athrady and other built-up frontages
Bus bay	Provided only at Athrady	Provide at Ontibettu and Hiriyadka bus stops also

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Capacity of the intersections — rotary design

Because a roundabout's capacity depends on how conflicting streams weave against one another rather than on the total approach volume alone, the appropriate input for the IRC weaving-section method is the classified, movement-wise flow at each approach rather than the aggregate figures reported in Table 1. Table 4 gives the PCU flow used for the rotary-design calculation at each approach, obtained from the classified turning-movement counts recorded during the design hour and shown schematically in Figures 4 and 5. These turning proportions, rather than the single-figure peak-hour totals, determine which pair of approaches forms the critical weaving section at each site.

Table 4. Approach-wise turning-movement PCU flow used for rotary design

Intersection	Approach	Left Turn (PCU/h)	Straight (PCU/h)	Right Turn (PCU/h)
Athrady	East	182	702	0
Athrady	West	0	903	253
Athrady	South	288	0	239
Hiriyadka	East	0	548	613
Hiriyadka	West	836	339	0
Hiriyadka	North	315	0	702

The two intersections show markedly different turning-movement patterns. At Athrady, through traffic dominates the West–East axis (903 PCU/h westbound, 702 PCU/h eastbound), while the South approach – the market road – contributes a comparatively modest but entirely turning volume (288 PCU/h left, 239 PCU/h right, with no through movement possible from that leg). At Hiriyadka, by contrast, turning volumes are concentrated on the West and North approaches: 836 PCU/h turn left from West onto North, towards the bus-stand road, and 702 PCU/h turn right from North onto West, while the West–East through movement is comparatively light at 339 PCU/h. This difference in movement structure — one lightly loaded turning approach at Athrady against two heavily loaded turning approaches at Hiriyadka — is what ultimately produces different critical weaving pairs at the two sites, as Figures 4 and 5 illustrate.

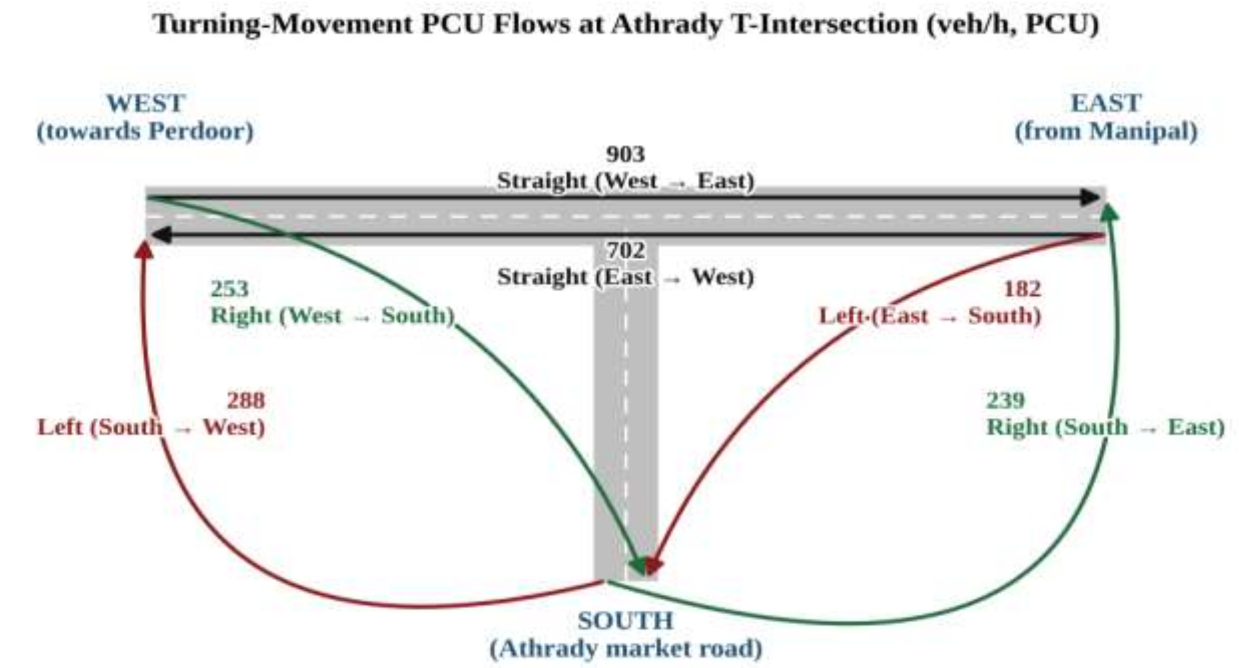

Figure 4. Turning-movement PCU flow diagram, Athrady T-intersection

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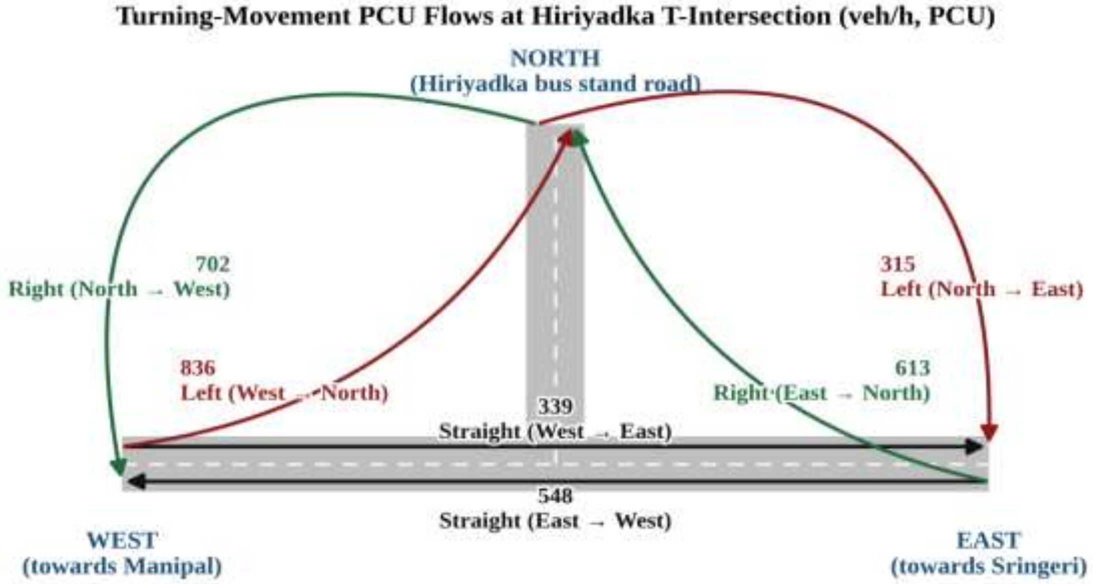

Figure 5. Turning-movement PCU flow diagram, Hiriyadka T-intersection

At Athrady, the East–South approach pair carries the highest proportion of weaving traffic (p = 0.84), while at Hiriyadka the critical pair is North–East (p = 0.77). With a weaving width of 8.5 m and a weaving length of 25.5 m at both sites, the resulting rotary capacities (Table 5) are 2,056 veh/h at Athrady and 2,092 veh/h at Hiriyadka — both comfortably above the observed peak-hour PCU volumes. Expressed as a degree of saturation, the critical peak-hour flow uses about 73% of the computed rotary capacity at Athrady (1,498 of 2,056 veh/h) but only about 41% at Hiriyadka (868 of 2,092 veh/h), so Athrady would operate appreciably closer to its theoretical limit even after conversion to a roundabout, while Hiriyadka would retain a substantial capacity margin. This indicates that a roundabout at either location would not itself be capacity-constrained, though the limited physical footprint available, particularly at Athrady where the junction is hemmed in by roadside shops, should be checked against the geometry assumed here before construction. The IRC weaving-section formula also assumes a uniform entry/exit width and free-flowing weaving conditions, and it does not directly account for the pedestrian and parking friction documented in the road-inventory survey (Section V.C); the capacities in Table 5 are therefore best read as an upper bound, achievable only if channelisation, marking and lighting are provided alongside the geometric conversion.

Table 5. Weaving-section parameters and rotary capacity

Parameter	Athrady	Hiriyadka
Weaving width, w (m)	8.5	8.5
Weaving length, l (m)	25.5	25.5
Avg. entry / exit width, e (m)	5.0	5.0
Critical approach pair	East–South	North–East
Proportion of weaving traffic, p	0.84	0.77
Rotary capacity, Qw (veh/h)	**2056**	**2092**

Traffic signal design — Webster's method

The flow ratios used below follow directly from the turning-movement counts in Table 4 and the phase groupings shown in Figures 4 and 5: at each intersection, the two non-conflicting movements sharing an approach are served in the same phase (for example, Athrady's South-leg left and right turns share Phase 3), consistent with the three-phase arrangement described in Section IV.E. For each phase, the design-hour flow

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qi is taken as the average of its two constituent movement volumes, and the corresponding flow ratio is Yi = qi / S, where the saturation flow S is read from the standard Webster-method saturation-flow table for the intersection's 3.5 m approach width, giving S = 1,890 PCU/h. Table 6 sets out this phase-by-phase derivation for both intersections; the resulting totals, Y = 0.67 at Athrady and Y = 0.86 at Hiriyadka, are carried forward into the cycle-time calculation in Table 7.

Table 6. Design-hour flow and flow-ratio derivation by signal phase

Intersection	Phase (approach)	Paired movements (PCU/h)	Design flow, qi (PCU/h)	Flow ratio, Yi
Athrady	Phase 1 (West)	Straight 903 + Right 253	578	0.3
Athrady	Phase 2 (East)	Straight 702 + Left 182	442	0.23
Athrady	Phase 3 (South)	Left 288 + Right 239	264	0.14
Hiriyadka	Phase 1 (West)	Left 836 + Straight 339	588	0.31
Hiriyadka	Phase 2 (East)	Right 613 + Straight 548	581	0.29
Hiriyadka	Phase 3 (North)	Right 702 + Left 315	509	0.26

Table 7 summarises the Webster's-method signal design for both intersections. At Athrady, a sum of critical flow ratios Y = 0.67 with a total lost time of 8 s per cycle yields an optimum cycle time of 52 seconds, apportioned as 20 s, 16 s and 10 s of green time (plus a 2 s amber interval per phase) across the three phases (Figure 6) — a cycle length well within normal practice for a three-legged junction of this size. At Hiriyadka, however, the higher flow ratio (Y = 0.86) drives the computed optimum cycle time to 121 seconds; even rounding this to a practical 120-second design cycle produces green times of 41 s, 38 s and 35 s per phase.

The near doubling of cycle time between the two sites is disproportionate to the underlying difference in demand, and this is a direct consequence of the shape of Webster's formula rather than of any additional traffic at Hiriyadka beyond what Table 4 already records. Because C0 = (1.5L + 5) / (1 – Y), the optimum cycle time is not linear in Y but rises asymptotically as Y approaches 1: with L fixed at 8 s, the numerator 1.5L + 5 = 17 s is constant, so C0 depends entirely on how close the denominator (1 – Y) is to zero. Moving from Y = 0.67 to Y = 0.86 raises C0 from 17/0.33 ≈ 52 s to 17/0.14 ≈ 121 s — a 133% increase in cycle time from what, on its own, might read as only a moderate 28% increase in the flow ratio. In practical terms, once an intersection's combined phase demand pushes Y into the upper end of its range, every further increment absorbs a disproportionately larger share of the available cycle, which is exactly the regime Hiriyadka's turning-movement pattern (Section V.D) places it in.

Table 7. Webster's-method signal design summary

Parameter	Athrady	Hiriyadka
Number of phases, n	3	3
Lost time, L = 2n + R (s)	8	8
Sum of flow ratios, Y = ΣYi	0.67	0.86
Optimum cycle time, C0, Webster (s)	52	121
Adopted design cycle (s)	52	120
Green times G1 / G2 / G3 (s)	20 / 16 / 10	41 / 38 / 35
Feasibility	Practicable	Not recommended – excessive cycle

Within each cycle, the green time allocated to a phase follows directly from its share of the total flow ratio, Gi = Yi(C0 – L) / Y, so a phase carrying a larger fraction of the design-hour demand receives a proportionally

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larger slice of the available green (Figure 6). The two sites differ in how evenly this allocation turns out: at Athrady the three phases receive 20 s, 16 s and 10 s of green, a roughly 2:1 spread between the busiest and lightest phase, consistent with the West–East through movement dominating that junction's demand (Section V.D); at Hiriyadka the split is far more even, at 41 s, 38 s and 35 s, reflecting a design-hour demand spread across two heavily loaded turning movements rather than concentrated in a single dominant direction. This more even split does not make Hiriyadka's signal design more workable, however, since it is the absolute cycle length – not its internal balance – that determines the wait a driver on any approach experiences.

This dependence on cycle length rather than internal balance follows directly from Webster's own average-delay model. The delay experienced by a vehicle on a given approach is

$$d = \frac{C(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} - 0.65\left(\frac{C}{q^2}\right)^{1/3} x^{2+5\lambda} \qquad (7)$$

where C is the cycle time, $\lambda = g/C$ is the proportion of the cycle allocated as green to that phase, $x = q/(s\lambda)$ is the degree of saturation, q is the arrival flow, and s is the saturation flow. The first term – the uniform delay assuming steady, undersaturated arrivals – is the term that dominates at both intersections studied here, and it scales directly with C: doubling the cycle time roughly doubles this component for a given green ratio, which is why the 120-second cycle at Hiriyadka imposes materially higher average delay than the 52-second cycle at Athrady even though both were sized using the same design principle.

Figure 6. Signal phase (cycle) timing diagrams for Athrady and Hiriyadka

A cycle length of the order computed for Hiriyadka carries a real operational cost beyond the formula itself. The uniform-delay component of Webster's own delay model (Equation 7) varies approximately with $C(1 - \lambda)^2$, where λ is the proportion of the cycle given to green on a phase, so simply lengthening the cycle – even at a fixed green ratio – increases the average wait every vehicle experiences. A 120-second cycle also means a driver arriving just after a phase turns red can face close to two minutes of waiting, which in mixed traffic dominated by two-wheelers and autorickshaws (Section V.A) creates a strong incentive to disregard the signal altogether, undermining the very safety benefit signalisation is meant to deliver. For this reason, a cycle length of this order is generally considered impractical for a rural three-legged junction of Hiriyadka's scale. Signalisation is therefore judged practicable at Athrady, where the 52-second cycle remains within normal

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design practice, but is not recommended at Hiriyadka, where the rotary design summarised in Table 5, combined with physical channelisation, is the more appropriate treatment.

Study limitations and directions for future work

The traffic-volume and speed-and-delay surveys reported here were each conducted over two consecutive days per intersection in March 2023, and the resulting peak-hour flows and speeds (Tables 1 and 2) should be read as characteristic of that survey window rather than as a year-round average. NH 169A carries a substantial pilgrimage and tourism traffic component, and coastal Karnataka experiences a pronounced south-west monsoon between June and September; both are likely to shift traffic volumes, vehicle composition and running speeds away from the values reported here, and weather itself has been shown to measurably affect incident-related delay independent of volume (Su et al., 2023). The present results are therefore best treated as a design-basis snapshot for typical dry-season conditions rather than an all-season average, and a repeat count during at least one monsoon period and one peak-tourist period is recommended to confirm that the Athrady and Hiriyadka treatments proposed here remain appropriate across the full annual cycle.

The road-inventory survey (Table 3) recorded the near-total absence of marked pedestrian crossings at both intersections, but the present study did not itself collect pedestrian volumes or apply a formal vulnerable-road-user delay model; the green-time allocation in Section V.E is accordingly based on vehicular flow ratios alone. Because Athrady fronts a market and Hiriyadka a bus stand, pedestrian demand at certain times of day may be substantial enough to warrant a dedicated pedestrian phase or an extended clearance interval, either of which could alter the cycle times and green splits reported in Table 7. A follow-up pedestrian count at both sites, feeding a combined vehicular-pedestrian signal design, is recommended before either treatment is finalised for construction.

Consistent with the surrogate-safety approach discussed in the literature reviewed in Section II.A, the present study infers safety deficiency from the geometric and control gaps identified in the road inventory (Table 3) rather than from historical crash records, which were not available to the authors at the time of this study. Obtaining three to five years of accident data from the local police or the regional transport authority for both intersections would allow the surrogate findings reported here to be checked against actual crash frequency and severity, and is recommended as a priority for any follow-up study or before final design sign-off.

Finally, the rotary and signal-timing capacities reported in Tables 5 and 7 follow from closed-form IRC and Webster's-method formulae, which necessarily simplify driver behaviour and the interactions between the heterogeneous vehicle types observed on this corridor. Before either the Athrady signal or the Hiriyadka roundabout is constructed, validating these theoretical capacities with a calibrated micro-simulation model – such as VISSIM or SIDRA, both of which support the mixed, non-lane-based traffic conditions typical of Indian highways – is recommended to confirm that the field-measured turning volumes translate into the delay and capacity outcomes predicted here.

CONCLUSION

This study quantified traffic conditions at two representative unsignalized T-intersections on NH 169A and evaluated engineering treatments for each. The key findings are:

- Peak-hour flow reaches 1,498 PCU/h at Athrady and 868 PCU/h at Hiriyadka, with two-wheelers and passenger cars together forming the dominant share of traffic at both sites.
- Running speeds along the corridor range from about 44 to 81 km/h, with the lowest and most asymmetric speeds occurring on the stretches passing directly through the two market / bus-stand frontages.
- A 28-parameter road-inventory survey found the corridor deficient in street lighting, crash barriers, guideposts, curve-warning signs and marked pedestrian crossings over most of its length.
- Rotary (weaving-section) analysis gives capacities of 2,056 veh/h at Athrady and 2,092 veh/h at Hiriyadka, both above current peak demand.

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- Webster's-method signal design gives a practicable 52-second cycle at Athrady but an excessive 120-second cycle at Hiriyadka; signalisation is therefore recommended only at Athrady, with a channelised roundabout preferred at Hiriyadka.

Together, these findings point to two clear priorities for NH 169A: signal installation with street lighting, crash barriers and pedestrian crossings at Athrady, and a channelised roundabout with matching lighting and delineation at Hiriyadka. Both measures speak directly to the safety gaps this study uncovered. The analysis itself has real limits, discussed fully in Section V.F: chiefly its two-day survey window, the absence of pedestrian counts and historical accident data, and its reliance on closed-form rather than simulation-based capacity estimates. Addressing these limitations, together with post-implementation monitoring once the recommended treatments are built, is the natural next step for this corridor.

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