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Smart Traffic Management Systems Under Heterogeneous Urban Traffic Conditions

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Abstract: *In this study, an experimental analysis of traffic performance at five major junctions of the urban network of Nagpur in heterogeneous traffic conditions is proposed. The analysis was carried out on the basis of the field-obtained traffic data of peak-hour traffic during the study at Jagnade Square, Shatabdi Square, Manewada Square, Laxmi Nagar, and Indora Junction. This paper focuses on five major signalized intersections that are selected at random in Nagpur, such as Jagnade Square, Shatabdi Square, Manewada Square, Laxmi Nagar, and Indora Junction, and evaluates their traffic performance experimentally. Variables collected for the manual surveys were converted to PCU by applying a set of IRC: 106 1990 equivalency factors, and analysed based on key performance indicators of degree of saturation (X = V/C) and Level of Service (LOS). Jagnade Square had the most effective demand (992 PCU/hr, X = 0.55, LOS C), followed closely by Shatabdi Square with an effective demand of 913 PCU/hr, X = 0.51, LOS C. For Manewada Square, the loading level is moderate (X = 0.37), and the loading level in Laxmi Nagar and Indora Junction is very low (X = approximately 0.23 - 0.24), and therefore, the same are considered as having LOS A.*

The key result is that, as demand grows; operational inefficiency at these hot junctions is not caused by a lack of capacity but by the need to have static signal timings for a variable demand. Shape of traffic mix - small and irregular nature of driving behaviour also reduces discharges at congested approaches. The shape of traffic mix - small and irregular nature of driving behaviour also reduces discharges at congested approaches. The study suggests a viable X and traffic variability-driven framework to identify the junctions where adaptive signal control is needed. It is designed to be low-cost and replicable in medium-sized cities in India, where infrastructure-intensive systems are a financial burden and not readily available in most cities.

Keywords: Traffic Engineering, Heterogeneous Traffic, Degree of Saturation, Adaptive Signal Control and Urban Traffic Management.

I. INTRODUCTION

Due to urbanisation and increased vehicle ownership, the road infrastructure of urban areas has increasingly been subjected to constraints from the growing use of road services, especially during peak hour, when signalised intersections are the most impacted. Historical use patterns and a static notion of demand are the basis for conventional fixed-time signal systems, which are unable to deal with the temporal variability that is typical of "real" urban traffic data. This is worsened in the general traffic scenario across Indian cities where commuters rely on bikes, cars, auto-rickshaws, buses, heavy vehicles, and other modes move around the same time with no uniformity in traffic discipline, which hampers the effective use of the road capacity, and increases delays during traffic operations.

This fact has led to a high research interest in the fields of adaptive and demand responsive signal systems. The average intersection delay (AID) for real-time optimised signals, and the throughput gain compared to fixed-time signals, is consistently found to be lower in field studies and in simulation research. A lot of the literature, however, assumes the

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presence of a network of IoT sensors, a set of AI-driven controllers, and a centralized traffic management system which are not common in Indian cities. The problem of financial, institutional and technological barriers hinders implementation of such systems in medium sized cities still.

Another recent and important lack in the literature is the lack of experimental, comparative tests performed under realistic traffic conditions (heterogeneous traffic conditions). Major cities are the focus of most field-based studies, with relatively limited focus given to medium-sized rapidly growing cities, but with similarly troublesome congestion issues. The underserved category is represented by Nagpur. Its population is roughly 3 million, it has irregular traffic patterns, high variability in levels of real-time demand, but nevertheless regularly suffers congestion at a handful of intersections, even though roadway network capacity on paper is heavy.

Field measurement and engineering analysis at five important junctions in the city of Nagpur, addresses these gaps in the present study. The specific goals are to:

1. Measure the effectiveness of the traffic using the standard measures (like PCU, X and LOS);
2. Determine the intersections where adaptive signal management is truly needed; and
3. Suggest a viable infrastructure for adaptation that are low cost and can be transferred to other cities in Indian context.

II. METHODOLOGY

The study adopts a non-simulative or non-modelling (direct traffic observation) analytical approach. The methodology has been carried out in the following stages as shown in a study framework flowchart in figure 1 and summarised as follows (see Table 2.1).

2.1 Site Selection

Five junctions have been selected from Nagpur's arterial road network based on the following conditions:

1. They can be geometrically analysed during the field survey.
2. Signalised control is available.
3. They are of importance within the urban road network and
4. There is a known behaviour of congestion.

The selected sites, namely Jagnade Square, Shatabdi Square, Manewada Square, Laxmi Nagar, and Indora Junction, are chosen as they have different intensities of demand and different profiles of vehicles in traffic. These are various sites of Jagnade, Shatabdi, Manewada, Laxmi Nagar, and Indora junction, which have different intensities of demand and different profiles of vehicles in traffic, so that a meaningful comparative analysis may be carried out.

2.2 Data Collection

The number of classified vehicles was manually counted in the morning and evening peak periods with video observation at strategic approaches. The vehicles were classified into 5 categories: 2-wheelers, cars/taxis, auto-rickshaws, buses, and trucks/LCVs. The times of cycles and phases for each junction were recorded simultaneously to aid discharge-level analysis.

2.3 PCU Conversion

Raw classified counts were converted to Passenger Car Units using IRC: 106-1990 equivalency factors: two-wheeler = 0.5, car = 1.0, auto-rickshaw = 1.5, bus = 2.5, truck/LCV = 2.5, bicycle = 0.5. PCU provides a standardised measure of effective traffic load that accounts for the different spatial and dynamic footprints of each vehicle class — a necessary normalisation given the highly heterogeneous composition observed at all study sites.

2.4 Performance Parameters

Three primary indicators were computed for each junction:

Traffic Volume and PCU/hr — absolute and normalised demand measures.
Degree of Saturation (X = V/C) — ratio of observed hourly PCU flow to intersection capacity, taken as 1800 PCU/hr for standard four-arm signalized intersections per IRC guidelines.
Level of Service (LOS) — qualitative grade (A through F) assigned according to the V/C ranges specified in the Highway Capacity Manual (HCM): A (≤ 0.20), B (0.21–0.40), C (0.41–0.60), D (0.61–0.80), E (0.81–0.90), and F (> 0.90).

2.5 Study Framework and Analytical Parameters

Table 2.1(a): Study Framework Components

Component	Parameter	Method	Purpose
Junction Selection	Representative urban intersections	Urban area screening, signal control	Comparative traffic analysis
Data Collection	Manual classified traffic survey	Video & manual peak-hour observation	Real-world traffic measurement
PCU Conversion	Mixed-traffic standardization	IRC: 106-1990 equivalency factors	Uniform analytical evaluation
Performance Analysis	V/C ratio and LOS computation	Volume–capacity assessment	Intersection efficiency rating
Comparative Evaluation	Junction-wise benchmarking	Cross-junction parameter comparison	Identification of critical locations
Strategy Formulation	Adaptive control prioritization	Demand-responsive threshold criteria	Practical management improvement

Table 2.1(b): Analytical Parameters and Their Role in the Study

Sr. No.	Parameter	Role in Analysis
1	Traffic Volume	Measures total vehicular demand at each approach
2	Passenger Car Unit (PCU)	Normalizes heterogeneous vehicles; enables realistic load comparison across sites
3	Degree of Saturation (X)	Quantifies operational loading relative to available capacity (V/C ratio)
4	Level of Service (LOS)	Translates V/C into qualitative performance grades A (free flow) through F (breakdown)
5	Traffic Variability	Captures sub-period demand fluctuations within the peak hour
6	Queue Characteristics	Describes congestion accumulation and discharge behaviour at signal approaches

2.6 Performance Classification

Junctions were classified by control requirement using the degree of saturation thresholds defined in Table 2.2, derived from standard traffic engineering practice and validated against field-observed congestion behaviour.

Table 2.2: Traffic Performance Evaluation Criteria

Sr.	Degree of Saturation (X)	Operational Condition	Control Requirement
1	X < 0.30	Stable, low-demand operation	Conventional fixed-time control is adequate

2	0.30 ≤ X < 0.50	Moderate operational loading	Selective signal optimisation warranted
3	X ≥ 0.50	Control-sensitive condition	Adaptive traffic management recommended

Classification thresholds for degree of saturation (X) and corresponding signal control requirements

III. RESULTS AND DISCUSSION

3.1 Traffic Volume and PCU Analysis The comparative traffic performance of all the five junctions are summarized in Table 3.1. The highest effective load measured was 992 PCU/hr at Jagnade Square (X = 0.55, LOS C) where the resulting delay was noticeable and affected by the timing of the signals. Shatabdi Square came in at 913 PCU/hr, but in a different fashion – queue formation functioned through volume, but the operational was to cut, rather than queue, as some would have traversed through this congested section. Manewada Square had an average level of 673 PCU/hr (X = 0.37, LOS B) and there was some degree of sub-period variation in peak hour which was evident. Capacity of Laxmi Nagar was roughly 0.23 (X = 0.23) and LOS (A) was very close to the nominal value; similarly at Indora Junction, X = 0.24 and LOS (A) were very close to nominal.

Table 3.1: Comparative Traffic Volume and PCU Analysis

Junction	Avg. Vehicles	Total PCU	Hourly PCU	Capacity (PCU/hr)	X (V/C)	LOS
Jagnade Square	283	198.4	992	1800	0.55	C
Shatabdi Square	227	182.6	913	1800	0.51	C
Manewada Square	168	134.6	673	1800	0.37	B
Laxmi Nagar	105	82.5	412	1800	0.23	A
Indora Junction	103	88.2	441	1800	0.24	A

Source: Field survey. Capacity assumed at 1,800 PCU/hr per IRC: 106-1990 guidelines.

It is significant to note that the raw vehicle count is not a good indicator for any operational stress. Although fewer vehicles were registered at Indora Junction as compared to Laxmi Nagar, it is interesting to note that its effective PCU seems to be higher, which points towards more auto-rickshaws and buses, among the registered vehicle fleet, than in the registered vehicle fleet of Laxmi Nagar. This will validate the need for PCU based analysis to be able to inter-compare different junctions, particularly when vehicle composition has as much of an influence on roadway occupancy as vehicle numbers in a heterogeneous setting.

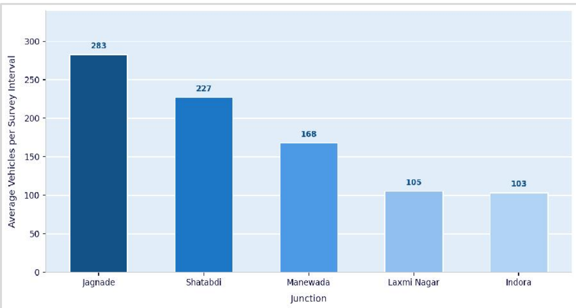

Figure 3.1 – Comparison of Average Traffic Volume at Selected Junctions

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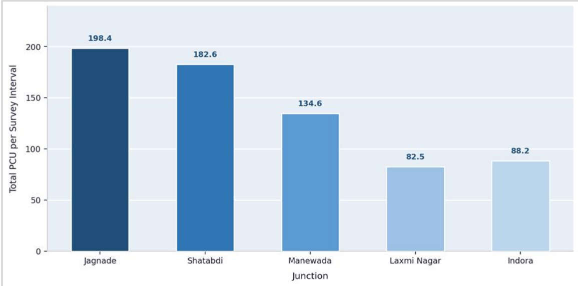

Figure 3.2 – Comparison of Passenger Car Unit (PCU) Across Selected Junctions

Figures 3.1 and 3.2 substantiate the demand hierarchy for these 5 sites. The shift from vehicle count (Figure 3.1) to PCUs (Figure 3.2) is most interesting at the Indora Junction, where the more buses and auto rickshaws, the higher the value of the PCUs in comparison to the number of vehicles, thus highlighting the significance of the change from vehicle count to the analytical concept of PCU.

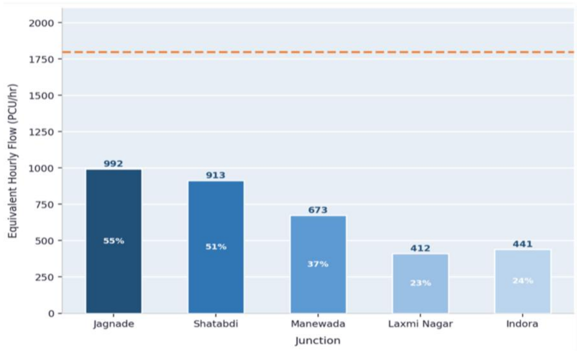

Figure 3.3 – Equivalent Hourly Traffic Flow (PCU/hr) vs. Intersection Capacity (1,800 PCU/hr)

The 1,800 PCU/hr capacity is shown in Figure 3.3 as a plot of PCU vs. the capacity. There's no over-saturation at any junction, but Jagnade and Shatabdi have 55% and 51% capacity use, respectively.

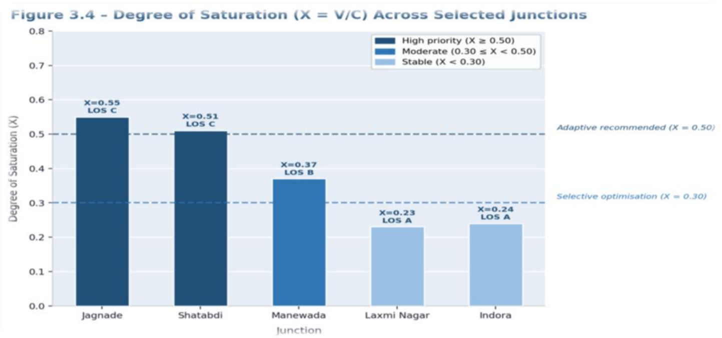

Figure 3.4 – Degree of Saturation (X = V/C) Across Selected Junctions

The X values observed, as applicable to the classification thresholds in Table 2.2, are directly applied, as in Fig. 3.4. Jagnade and Shatabdi are in the adaptive-recommended band ($X \geq 0.50$), and Manewada is in the selective-optimisation band ($0.30 \leq X < 0.50$); the two other junctions are in the stable zone ($X < 0.30$). This visual mapping gives a visual and practical foundation for investment prioritisation.

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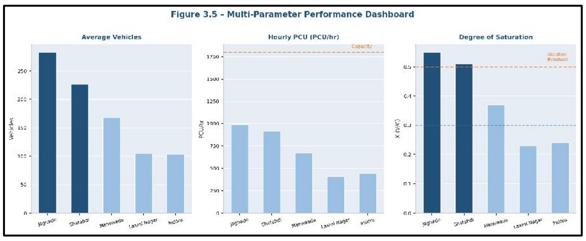

Figure 3.5 shows a Multi-Parameter Performance representing Traffic Volume, PCU/hr and Degree of Saturation.

Figure 3.5 combines all three of the main indicators into a single comparative image for the 5 junctions a ranking is consistent across all both indicators and relative position is immediately interpretable for traffic management decision making.

3.3 Identification of Junctions Requiring Adaptive Traffic Management

Each junction type observed has been classified according to the classification criteria defined in Table 2.2 and categorised with field observations of the type of discharge and demand pattern, and given a recommended management type or strategy based on these classifications in Table 3.2.

Table 3.2: Adaptive Traffic Management Requirement Assessment

Junction	Traffic Behaviour	X Value	Priority	Recommended Strategy
Jagnade Square	Sustained demand accumulation	0.55	High	Adaptive signal timing with real-time phase adjustment
Shatabdi Square	Continuous directional loading	0.51	High	Dynamic phase optimisation; turning movement management
Manewada Square	Temporal demand variability	0.37	Moderate	Selective adaptive control during peak sub-periods
Laxmi Nagar	Stable low-demand operation	0.23	Low	Optimised fixed-time control with periodic review
Indora Junction	Balanced, low-stress flow	0.24	Low	Conventional signal operation is sufficient

Priority classification based on observed X values, LOS grades, and demand variability characteristics

The primary mechanism at Jagnade Square is “accumulation of demand” this means that the amount of traffic at the intersection does not decrease cleanly between successive cycles, and that the existing fixed-time plan does not reflect the real-time variation in traffic at the intersection. The solution is adaptive signal timing (AST), which changes the length of the cycle and the length of green splits in response to measured demands.

Shatabdi Square is a different kind of challenge; it's not just about the volume but about the continual directional loading and manoeuvring. Phase sequencing and green-time distribution throughout competing movements need to be flexible and to prioritise phase optimisation over increased amounts of green time.

Today, Manewada Square is moderately saturated but has clearly higher intra-peak variation, which would indicate a greater sensitivity to increased demand. The selective adaptive control, which is intervention in the highest demand sub-periods and not across the entire length of the cycle, represents a cost-effective approach, which is suitable for an intervention that is not yet fit for full adaptive control.

No urgent action is needed for Laxmi Nagar and Indora Junction except to periodically adjust their fixed-time plans. They have the capacity to meet the widespread variability in demand and maintain service quality.

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3.4 Discussion

The results clearly indicate that the inefficiency encountered at the study junctions is not a capacity issue. All five intersections operate below their 1,800 PCU/hr theoretical capacity. The improper matching of static signal timing to dynamic traffic demand is what causes congestion at the higher-demand sites, and is where adaptive control directly intervenes to solve that problem, at a much lower cost than expansion.

This is exacerbated by the different types of traffic composition. The presence of two-wheelers, auto-rickshaws, and cars in a discharge queue without lane discipline and with no consideration for variations in start-up delay, lateral spread, or non-uniform acceleration profile provides delivery lost-time that exceeds the estimates of fixed-time plans. Therefore, the traditional demand-based approach using PCU could underestimate the effect of operational sensitivity; there will be two independent variables to consider in signal design for heterogeneous environments: discharge inefficiency, in addition to approach volume.

The results are consistent with the ongoing literature in the field of adaptive signal control in Indian contexts, in that moderate-saturation intersections with variable demands yield greater benefit from timing changes that accommodate traffic demand, as opposed to investment in new infrastructure. The engineering approach suggested here, based on field-measurable indicators (X, LOS, traffic variability) that can be calculated using standard manual survey data, offers a practical screening tool that can be used by cities that do not have access to expensive sensor networks.

3.5 Limitations

There are several caveats that must be noted. First, traffic data have only been taken for a small number of peak hours - demand cannot be measured seasonally or day-to-day. Secondly, it was assumed that the capacity of all the linkages is uniform at 1,800 PCU/hr; however, some junctions may have different capacities depending on the lane (for lane parameters, please refer to the "Capacity estimation" section below), turning geometry, and degree of pedestrian interaction (site-specific capacity estimation would improve X calculations). Thirdly, manual vehicle classification also contains some observer variability, which could be eliminated with automated, video-based classification. Last, the analysis is confined to just five junctions; it would be more valuable to have a larger sample to increase the generalisability of the threshold-oriented approach.

IV. CONCLUSION

The present study applied performance measures, including PCU, the degree of S, and LOS of five intersection locations in Nagpur when heterogeneous traffic is present at the intersections. These are the conclusions:

1. Presently, there are no alternatives identified for either 1, Jagnade Square (X = 0.55, LOS C) or 2, Shatabdi Square (X = 0.51, LOS C) – both of which are considered most critical for adaptive signal management. Their congestion systems are different: there is a system of congestion accumulation with the former and a persistent directional congestion with the latter; hence, the interventions of these two systems should be different.
2. Manewada Square (X = 0.37, LOS B) may require selective adaptive control, but with a focus on peak sub-periods, especially because of the intra-hour demand fluctuations that have been observed at this site.
3. Fixed-time control is adequate at the present time (LOS A) for 3) Laxmi Nagar and Indora Junction (X ≈ 0.23–0.24).
4. Signal-demand mismatch and heterogeneous composition effects (not capacity shortage) are responsible for operational inefficiency at the congested sites. Adaptive control investment gives greater operational returns per rupee than the geometric roadway expansion at these locations.
5. It is important to note that in cases of mixed traffic operation (heterogeneous traffic), the vehicle composition may be very different between sites, necessitating PCU normalisation for significantly defensible inter-junction comparison.
6. Degree of saturation, LOS, and traffic variability, together, serve as enough of an engineering basis to prioritise adaptive signal control investment, without investing in costly sensors or AI infrastructure.

7. Beyond volume-based indicators, behavioural factors, like irregular lane and random stopping, non-uniform acceleration, are a significant source of discharge inefficiency and should be considered when designing signals for heterogeneous environments.

The analytical framework developed in this study is designed to be low-cost and easily reproducible with common manual survey equipment and simple traffic engineering computation. It is suitable as a first-pass screening solution for traffic authorities in medium-sized Indian urban areas, aiming at rationalising investments in adaptive signal management across large junction networks.

FUTURE SCOPE

The following extensions would enhance the nature of this work and its usefulness for analysis and application:

- Embracing camera-based or IoT sensor input to allow continuous demand monitoring through high resolution, and real-time signal adjustment at priority junctions.
- Developing an ability to predict traffic demand over shorter time horizons with models (either machine learning or statistical) for signal adaptation in a proactive, not reactive, manner.
- Extension to isolated junction analysis, including the “green wave” effect, spillback and interaction between junctions for arteries.
- Empirical validation of the proposed framework by implementation and controlled before and after assessment of adaptive signalling at the 2 pilot sites, Jagnade and Shatabdi.
- Increased inclusion of pedestrian flow, on-street parking occupancy data, and public transport dwell time in the behavioural capacity model for intersections for more comprehensive performance assessments.
- Construction of emergency vehicle pre-emptive and incident management strategies as part of an adaptive control structure.
- The analysis during the season and off the season to check if fixed-time plans were sub-optimal during periods other than the mornings and evenings studied here.
- Replace the assumption that capacity is 1,800 PCU/hr with estimates based on geometry at each junction; measure saturation flows to achieve this.

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REFERENCES

No.	Author(s)	Title	Journal / Conference	Year
1	M. Bawangaonwala et al.	A review on development of intelligent transport system to compare with Nagpur transport system	Int. J. Computer Science and Mobile Computing, vol.7, no.4, pp.12–21	2018
2	A. Kumar B. P. et al.	Implementing smart control of traffic light system using artificial intelligence	IJARSCT, vol.3, no.8	2023
3	A. Kanungo et al.	Smart traffic lights switching and traffic density calculation using video processing	Proc. RAECS, Chandigarh, pp.11–34	2014

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4	A. Miyim and M. Muhammed	Smart traffic management system	IEEE	2019
5	K. A. Wairagade et al.	AI-powered smart traffic management system for urban congestion reduction	Int. J. Scientific Research & Engineering Trends	2025
6	A. A. Ouallanea et al.	Overview of road traffic management solutions based on IoT and AI	Proc. IWIT	2021
7	A. L. Chaudhuri and L. Nakade	Smart traffic management using Faster R-CNN deep learning method	—	2024
8	A. K. Pipersenia	A review on smart traffic light control systems	Int. J. Food and Nutritional Sciences	2022
9	S. T. Bhuvan et al.	Smart traffic management system: A literature review	IJIREEICE	2022
10	K. K. Chandana et al.	Smart traffic management for congestion control using IoT	Saudi J. Engineering and Technology	2017
11	P. C. Gawali et al.	Effective traffic management using hydraulic footpath	Int. J. Scientific Research in Science and Technology	2020
12	G. A. Selvi et al.	Smart traffic control system using artificial intelligence	IJFMR	2024
13	M. Jena et al.	Intelligent traffic monitoring and signaling for smart cities	Int. J. Engineering and Science Invention	2021
14	N. Lanke and S. Koul	Smart traffic management system	Int. J. Computer Applications	2013
15	V. Mahavar and J. Juremalani	Literature review on traffic control systems used worldwide	J. Emerging Technologies and Innovative Research	2018
16	J. Mehta et al.	Smart traffic management system	Int. J. Novel Research and Development	2022
17	M. S. Naik et al.	Smart traffic management system	IJRASET	2023
18	N. Jain et al.	Agent-based intelligent traffic management for smart cities	Int. J. Smart Home	2015
19	S. G. Farrag et al.	A smart traffic incident management framework	J. Ambient Intelligence and Humanized Computing	2021
20	S. Teware et al.	Smart traffic management using IoT sensors	Int. J. Innovative Research in Technology	2024