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Analysing the role of Dwarka Expressway in alleviating congestion on the Delhi-Gurgaon Expressway using YOLOv11 and counterfactual modelling

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Abstract

Extremely high demand for vehicular movement, minimal inter-connectivity via public transportation and lack of new thoroughfare expansion on the Delhi-Gurgaon Expressway has been a recurrent problem since its inauguration in 2008, failing to cater to the explosive demand. 18 years since then, this problem has only increased, overloading the link between both the megalopolises. To transfer this increasing load of vehicular movement and cater to an expanding Gurgaon, the Dwarka Expressway was constructed offering a second entry point into the city from South West Delhi allowing vehicles an alternate route with the motive to reduce congestion on Delhi-Gurgaon Expressway. Through YOLO computer vision model-based traffic analysis in a counterfactual framework, this study aims to identify whether Dwarka Expressway has led to reduced traffic on the Delhi-Gurgaon Expressway or not. Counterfactual modelling allows projected values of the expressway congestion in absence of Dwarka Expressway to be synthesised and compared with actual figures of Aug-Sept 2025 and Dec-Jan 2025. A difference-in-difference and deviation analysis shows that only the Gurgaon section of Delhi-Gurgaon Expressway has experienced some congestion relief as four wheelers and heavy motor vehicles have deviated to Dwarka Expressway, leaving the Delhi section of the expressway mostly untouched.

Keywords: Congestion, expressway, Gurgaon, passenger car units, counterfactual

1. Introduction

Gurgaon, originally a small agricultural village started on its path to development in the 1970s when the Haryana Urban Development Authority was created (1977), Gurgaon was split away from Faridabad administratively (1979), Development and Regulation of Urban Areas Act of 1975 made land acquisition easier, Delhi Lease and Finance (DLF) started buying up agricultural wasteland to develop townships (1979) and most notably, when the Maruti-Suzuki joint venture led to the setting up of an automobile plant in Gurgaon (1982). (Rajagopalan & Tabarrok, 2014). The inflow of factories and ancillary industries coupled with the strict zoning policies set up by the Delhi Development Authority led to the large-scale relocation of offices and people to Gurgaon in search for affordable housing and employment starting in the 1980s. To travel between Delhi and Gurgaon, one used the now called Old Delhi-Gurgaon Road and the MG Road (NH 148A). This network connects Kapashera in Delhi to Mahavir Chowk in Old Gurgaon, falling right where the Maruti-Suzuki factory is situated and Mehrauli to New Gurgaon. It was only in 1997, when the existing National Highway 8 (Now NH-48) was sanctioned to be widened and converted into an access-controlled section between Delhi's Dhaula Kuan and Gurgaon's Kherki Daula. Growing traffic between the two cities and the overall rising volume of traffic as between the metros of Delhi, Mumbai, Chennai and Kolkata facilitated this decision and led to the creation of the Golden Quadrilateral, within it the Delhi-Gurgaon Expressway on NH-48 (National Highways Authority of India & RITES, 2001) ^[14]. The national highway initially fell on the outskirts of Gurgaon (now Old Gurgaon) and lacked the importance it has today. Land acquisition and construction of office complexes, malls, residences, the golf course etc. over the years gave it the centre position as the primary road network between the two megalopolises. The project would cater to the high passenger car volume that moves between Delhi and Gurgaon while also supporting freight that needs to reach the ports of Mumbai from Delhi.

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Close to 150,000 cars (Singh, 2010) ^[20] were using the expressway daily in 2010 compared to the 97,000 motorised vehicles which entered the highway from Delhi during the detailed-project report traffic survey in 2000 (National Highways Authority of India & RITES, 2001) ^[14]. It was determined that the initial traffic surveys vastly underestimated the traffic flow through toll gates, which were now causing congestion issues. Problems of toll operations, highway maintenance also popped up due to several legal battles between the construction companies Jaiprakash Industries, DS Constructions and NHAI. (Singh, 2010; Garg, S., & Mahapatra, D. 2017) ^[20, 7]. Only two years after the red ribbon was cut, the time taken to cross Delhi-Gurgaon Expressway doubled to 40 minutes with crossing the toll taking as long as fifteen minutes (Das, 2003) ^[3]. Using the annual traffic growth rates given by NHAI in 2001, we conclude the estimated vehicle movement to be somewhere between 275,540 PCUs per day in Gurgaon and 480,000 PCUs per day in Delhi as of 2025. The same highway which accommodated roughly 100,000 PCUs in 2000 before its upgradation and 160,000 PCUs in 2010 now carries close to five times that amount. It is safe to say that the strain on the Delhi-Gurgaon Expressway has only surged and will continue to do so without interventions.

In 2006, in an effort to alleviate this long-standing issue of congestion on the Delhi-Gurgaon Expressway and offer another viable entry into Gurgaon, the Dwarka Expressway also known as the Northern Peripheral Road was planned (National Highways Authority of India & AECOM, 2017; Dutta, 2018) ^[13, 6] as an access-controlled expressway connecting the sub-city of Dwarka, Old Gurgaon and NH-48 altogether. This expressway starts from Dwarka Sector 21 in Delhi with one branch connecting the Delhi-Gurgaon Expressway in Shiv Murti whilst another branch joining the Southern Peripheral Road near Sector 74A Gurgaon (National Highways Authority of India & AECOM, 2017) ^[13]. After several delays with construction and most notably land acquisition (Dutta, 2018; Som, 2025; Kumar, 2012) ^[6, 21, 10], the Dwarka Expressway opened to the public in March 2024 while the section in Delhi opened in August 2025.

However, it remains to be seen whether the construction of Dwarka Expressway has truly reduced the burden on the Delhi-Gurgaon Expressway or not. To find this out, the study goes on to compare two sets of traffic data on both expressways within a counterfactual framework, to interpret whether traffic has been diverted from one road to another since the Dwarka Expressway's complete inauguration in August of 2025. Together with the projected counterfactuals and real data sets, an inference can be made as to whether traffic diversion has taken place from the former to the latter or not.

2. Related literature

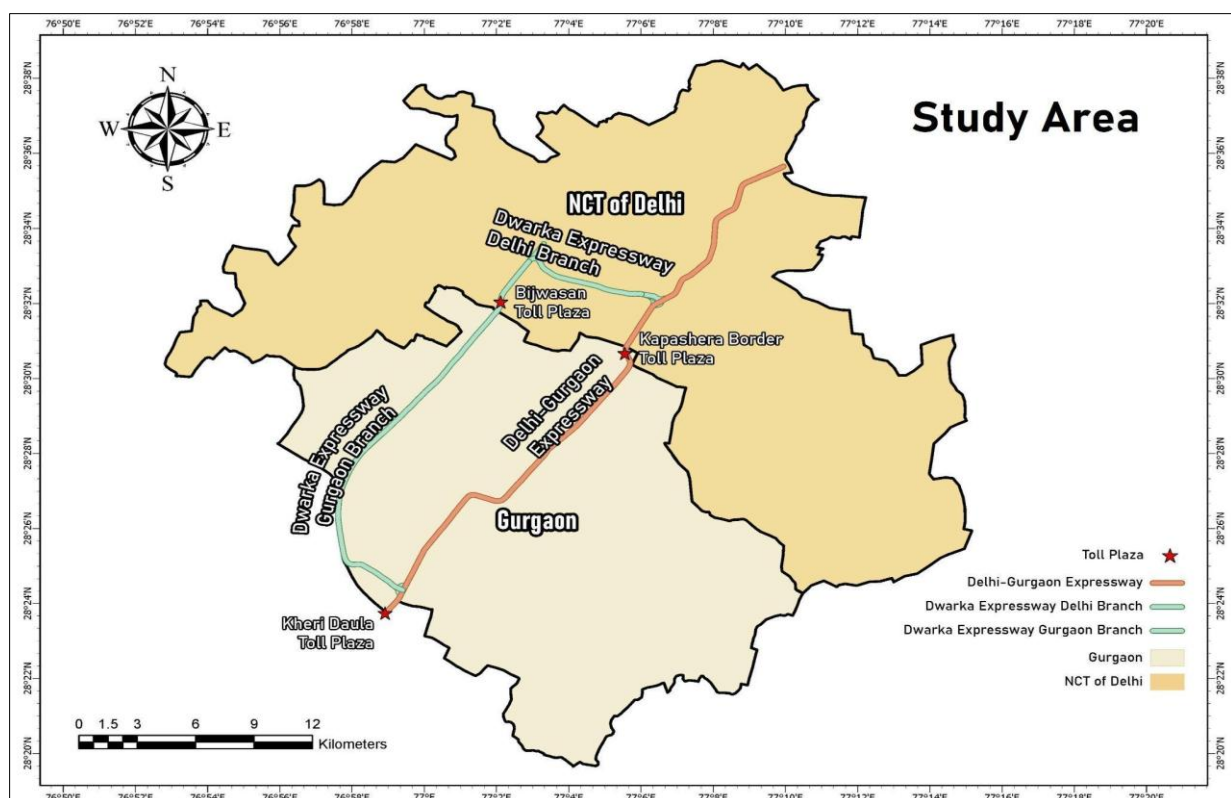
Existing work on computer-vision based traffic congestion analysis and historic congestion analysis on the Delhi-Gurgaon Expressway was utilised to develop the methodological basis for estimating traffic flow on the Delhi-Gurgaon Expressway both prior to and following the construction of the Dwarka Expressway. The first section of literature analysis consists of the work done in computer-vision based and manual traffic count analysis. Kunekar *et al.* (2023) ^[11] details the process about how to utilise the seventh version of the compute-vision model known as YOLO in traffic management. The implementation of YOLOv7, which

is noted for its improved detection accuracy and computational efficiency compared to earlier versions. The authors discuss how YOLOv7 enhances feature extraction and prediction through optimised network architecture, making it effective in complex traffic environments. Experimental results presented in the paper indicate that the proposed system achieves reliable vehicle detection performance under varying traffic conditions, supporting adaptive signal control, suitable for the high and variable traffic movement on the Delhi-Gurgaon corridor. While the paper does not introduce a novel detection algorithm, it contributes to applied research by validating the use of YOLOv7 in real world traffic management scenarios. Bakirci (2024) ^[1] mentions that shaded environments prove to be a stumbling block for the YOLOv8 algorithm, leading to instances of missed car and motorcycle detection. The algorithm encounters obstacles when confronted with complex real-world scenarios. Motorcycle detection exhibits relatively high precision, but there is limitation attributable to the wide variation in motorcycle shapes and visual appearances, which can result in occasional misclassifications. In contrast, bicycles record the lowest precision among all object classes, highlighting the algorithm's considerable difficulty in reliably distinguishing bicycles from other objects in the scene. The lowest precision value among all classes is observed for bicycles, indicating a notable struggle in correctly identifying bicycles. Further analysis reveals consistent misidentifications, such as vans being frequently mistaken for cars. Moreover, a distinct trend emerges where trucks are inaccurately identified as buses or vans, attributed to the intricate nature of truck trailers. Various factors, including viewing angles and obscured trailers, contribute to instances where trucks resemble vans. Kurle *et al.* (2016) ^[12] article on lane utilisation and Pathak *et al.* (2020) ^[15] work on traffic count helps with understanding the traffic composition and movement on the Delhi-Gurgaon Expressway and Gurgaon in general. It helped this study identify a key survey location in Gurgaon and set a baseline on the principles to be used while surveying traffic such as converting vehicle counts using PCU factors, choosing level terrain, removing pedestrian or road impediments which can act as unknown variables influencing traffic flow. Puvvala *et al.* (2013) ^[16] and Chandra *et al.* (2017) ^[2] both provide empirical estimates of the capacity of an eight-lane divided urban expressway operating under mixed traffic conditions in India. Using a calibrated microscopic simulation model developed in VISSIM, Puvvala *et al.* (2013) ^[16] estimated the directional capacity of the Delhi-Gurgaon Expressway to range between approximately 9,700 and 11,500 PCU/h/dir, depending on lane utilisation behaviour and the formation of virtual lanes under heterogeneous traffic conditions. Their findings highlight that vehicle composition, non-lane disciplined movement, and lateral interactions play a significant role in determining effective expressway capacity. In contrast, Chandra *et al.* (2017) ^[2] derived capacity estimates using speed flow relationships developed specifically for eight lane divided urban expressways in India. Based on empirical speed flow curves and observed traffic characteristics, they reported lower capacity values, with estimates starting from approximately 7,625 PCU/h/dir. The reduced capacity values reflect the influence of high traffic heterogeneity, speed differentials among vehicle classes, and frequent lane changing manoeuvres that disrupt stable flow conditions.

The second set of works referred to are primarily concerned about Gurgaon's development and historic traffic problem. Saxena and Choudhury (2022) ^[19] findings indicate that congestion in Gurugram is primarily driven by high dependence on private transport, inadequate public transport coverage, and inefficient utilisation of existing road infrastructure. Peak hour traffic conditions are characterised by reduced travel speeds, increased delay, and unstable traffic flow, particularly in commercial and employment intensive zones. The study highlights that congestion costs are disproportionately borne by all road users, including public transport passengers, despite being generated largely by private vehicle users. Using economic valuation techniques, the authors estimate congestion costs in terms of travel time losses and increased vehicle operating costs. The results reveal that congestion imposes substantial economic burdens on commuters and the urban economy, reinforcing the argument that current travel behaviour does not reflect true social costs. Congestion externalities escalate rapidly as traffic volumes approach or exceed roadway capacity, showcasing the geometric relationship between traffic demand and congestion impacts. Gurgaon's history of private development and lack of civic infrastructure to support the enormous growth of both housing and vehicular traffic is captured beautifully by Goldstein (2016) ^[9] in 'Planning the Millennium City: The politics of place-making in Gurgaon, India' where she argues prioritisation of real estate driven growth and commercial developments occurred without proportional investment in transport planning. The rapid concentration of office complexes, gated residential communities, and shopping centres generated high travel demand, particularly for private motorised transport. In the

absence of a strong public transport backbone during the city's formative growth phase, Gurgaon developed a pronounced dependence on private cars and two wheelers, which significantly contributed to congestion on arterial roads and expressways. Similarly, Garg and Mahapatra (2017) ^[7] further state that the Delhi-Gurgaon Expressway's historic congestion problems come not only from high traffic demand but also by poor contract design and opportunistic practices by the concessionaire. Toll plaza placement, inadequate lane management, and insufficient capacity augmentation were identified as key contributors to severe congestion, resulting in excessive delays and public dissatisfaction. The expressway initially lacked connection with surrounding villages, overbridges to facilitate pedestrian movement and access control to maintain speed of vehicles. An analysis of the combination of these works on traffic surveys and Gurgaon's development and congestion problem provides the necessary methodological foundation and contextual background to undertake the present traffic survey. The existing literature highlights the influence of mixed traffic conditions, rapid urban development, and governance related factors on congestion levels in Gurgaon, while also identifying gaps in conventional data collection approaches. Building on these insights, this study employs YOLOv11 to estimate traffic volumes and vehicle class distributions, keeping in mind its faults and limitations. The resulting figures are then compared with counterfactual scenarios generated using traffic growth projection rates provided by the National Highways Authority of India, enabling an assessment of observed traffic conditions against expected trends.

3. Study area



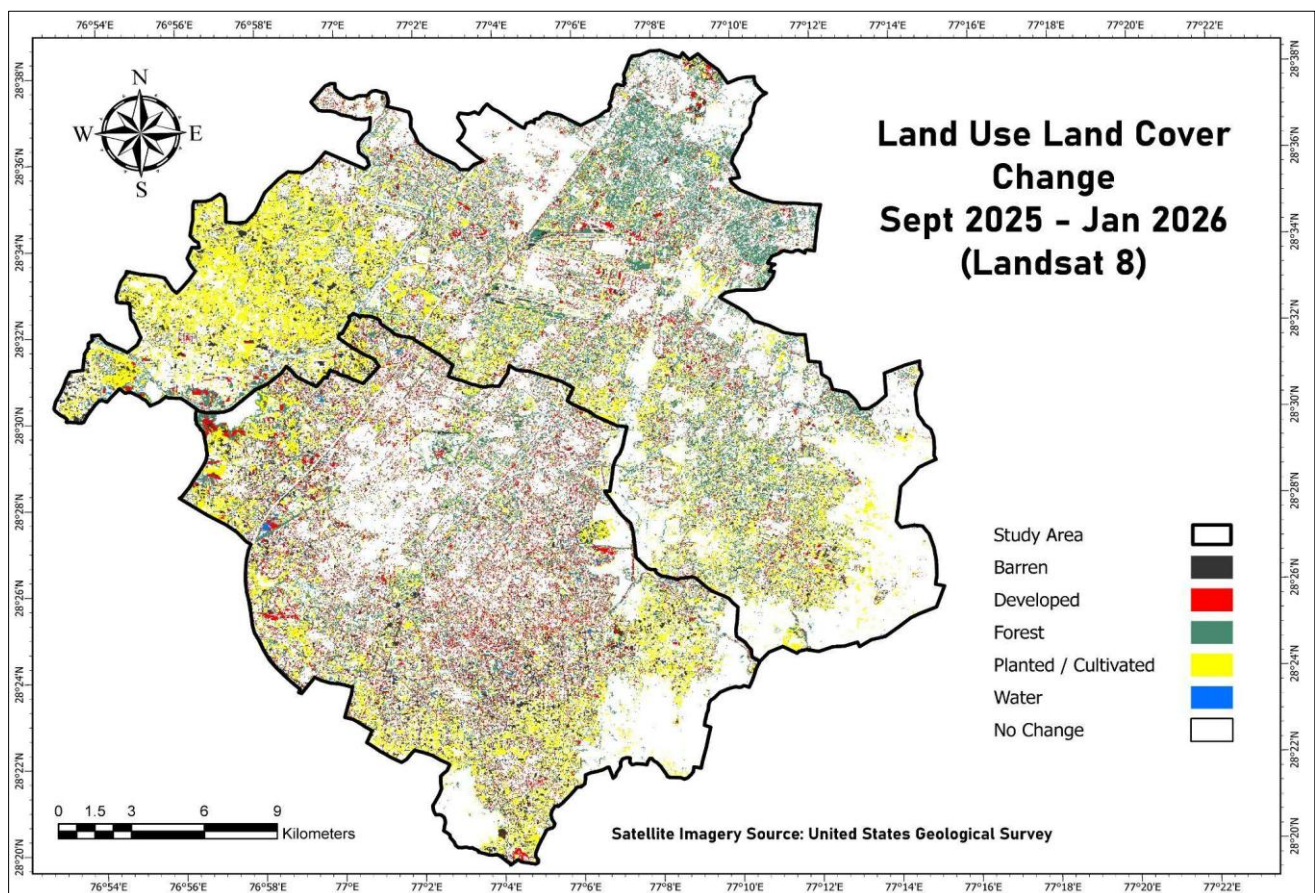
Note: This map represents the Kapashera, Dwarka, Delhi Cantt, Vasant Vihar, Mehrauli and Saket Tehsils situated inside South West, New Delhi and South Delhi Districts. Within Gurgaon district, the area depicted is one that falls under the Gurgaon Municipal Corporation Area

Fig 1: Study area

The study area (Figure 1) extends from 28.611726° N, 77.042488° E in Dwarka, Delhi to 28.395917° N, 76.982194° E near the Kherki Daula Toll Plaza in Gurgaon, encompassing a significant stretch of the Delhi-Gurgaon corridor. Gurgaon, officially referred to as the Municipal Corporation of Gurgaon together with its outgrowth areas, lies in the south-eastern part of the state of Haryana and falls administratively under the Gurgaon tehsil. Portions of its urban boundary also extend into the adjoining tehsils of Badshahpur, Wazirabad, Harsaru and Kadipur within Gurgaon district (Department of Revenue & Disaster Management, Government of Haryana, 2021) [5]. The city shares its northern boundary with the National Capital Territory of Delhi, forming one of the most economically significant inter-state urban borders in India.

The Delhi segment of the study area consists of narrow territorial strips belonging to the South West, New Delhi and South districts. Within these districts, the study area specifically includes the localities and tehsils of Kapashera, Dwarka, Vasant Vihar, Delhi Cantonment, Mehrauli and Saket. However, since the demographic and administrative datasets used in this study are drawn from the 2011 Census, some of these jurisdictions were recorded under their earlier tehsil names, namely Najafgarh, Vasant Vihar, Hauz Khas and Kalkaji. The boundary belt separating Delhi from Gurgaon primarily comprises green zones, vacant government land and small, dispersed village settlements, creating a peri-urban landscape (Delhi Development Authority, 2021) [4].

4. Methodology



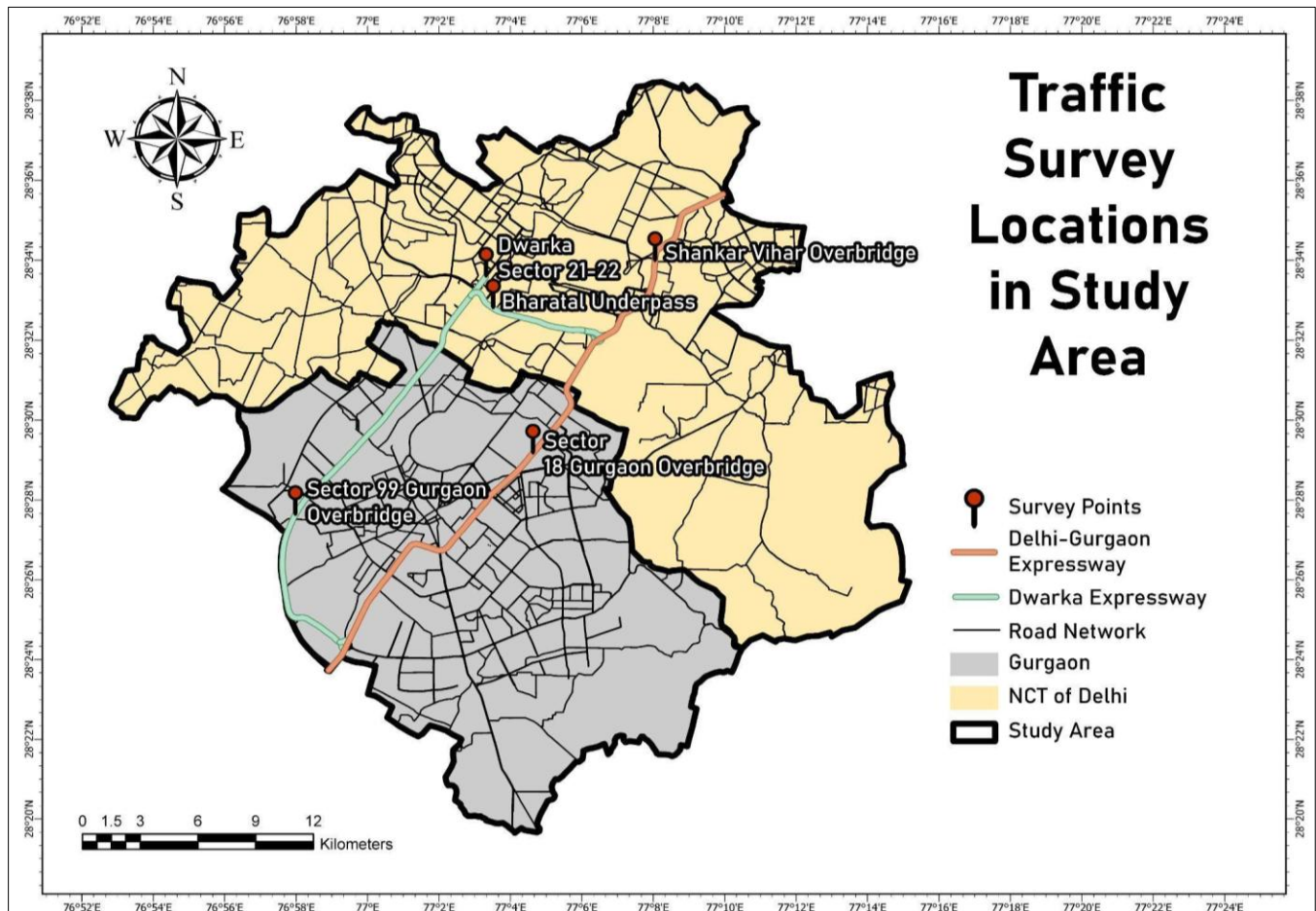
Note: Map prepared using Level-2 satellite imagery from Landsat 9 (September 2025 and January 2026), obtained from the U.S. Geological Survey (USGS)

Fig 2: Land use land cover change analysis (September 2025 - January 2026)

The study aims to understand whether traffic has been diverted from Delhi-Gurgaon Expressway to Dwarka Expressway following its opening by comparing passenger car unit (PCU) values from Aug-Sept 2025 and Dec-Jan 2025-26 to their counterfactuals i.e. the projected values of traffic estimated by NHA during their construction. To establish causation, a LULC change map has also been constructed using Landsat 8 satellite imagery, shown in Figure 2 proving that no significant developments or creation of road networks have taken place during this time redirecting flow from Delhi-Gurgaon Expressway or Dwarka Expressway. The majority of change observed in this period is in planted area and forest/vegetation cover which shifts

periodically as cropping seasons begin and end. Minor change in built-up area increasing/decreasing can be attributed to classification errors as the spatial resolution and spectral range of the imagery remains limited. Large deviations from counterfactuals indicate that the expressway is under-performing (negative deviation) or overburdened (positive deviation) whereas variations in values between Aug-Sept and Dec-Jan will show whether traffic has been diverted or not. Lastly, a difference-in-differences analysis is performed on the deviations to mathematically understand how much of excess demand has Dwarka Expressway catered to and how much relief has Delhi-Gurgaon Expressway experienced.

4.1 Data collection and extraction

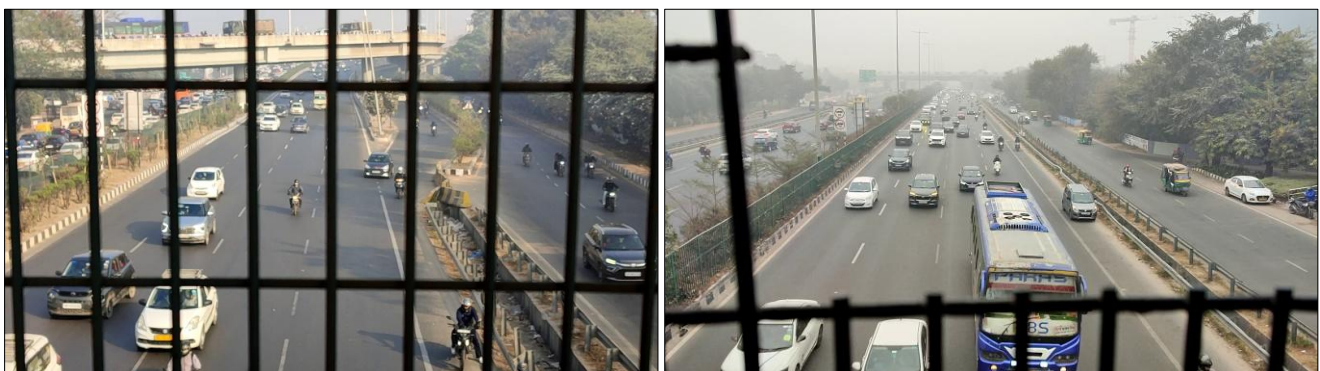


Note: Map adapted from OpenStreetMap road network data downloaded from GeoFabrik (Northern Zone, India). © OpenStreetMap contributors

Fig 3: Traffic survey locations in study area

Both Delhi-Gurgaon Expressway and Dwarka Expressway begin in Delhi and end at Gurgaon, thus, to collect traffic data five locations for survey were selected to cover areas in Delhi and Gurgaon, shown in Figure 3. On the 6/8-lane semi-access-controlled Delhi-Gurgaon Expressway, traffic footage was collected at Shankar Vihar in Delhi and Gurgaon Sector-18 in Gurgaon, due to the presence of foot-over bridges to set up cameras. On the Dwarka Expressway, data was collected at Dwarka Sector 21-22, where the Dwarka Expressway begins, Bharatal Underpass in Delhi where the branch segment of Dwarka Expressway connects to Delhi-Gurgaon Expressway at Shiv Murti and finally Gurgaon Sector-99 in

Gurgaon. The locations on Dwarka Expressway were chosen due to their convenience in providing vantage points in Bharatal and Gurgaon Sector-99. A foot-overbridge was not available in Dwarka thus footage was recorded from the footpath, just where the expressway ramp begins. Figure 4 depicts all the survey locations clearly. Footage was recorded from 0900 to 1100 in the morning and 1400-1600 in afternoon where one hour was given to each direction at each location, capturing both peak and off-peak values. It was also made sure that the roadway sections selected to survey were of level terrain and had no pedestrian or encroachment obstructing flow.





Note: (Top-Left) Shankar Vihar Overbridge on NH-48, (Top-Right) Gurgaon Sector 17-18 on NH-48, (Middle-Left) Dwarka Sector 21-22 on Dwarka Expressway, (Middle-Right) Bharatal Underpass on Dwarka Expressway and (Bottom) is Gurgaon Sector-99 on Dwarka Expressway

Fig 4: Traffic survey locations

After collection of footage, vehicular counts were calculated using the YOLOv11 model. A pre-trained computer-vision model, YOLO specialises in object detection and tracking, with the ability to count anything from objects like plants and telephones to different types of vehicles. The v11 model was chosen for its improved backbone and neck architecture, optimised training pipelines, higher mean Average Precision (mAP) on the COCO dataset (Ultralytics, 2026)^[22] making it computationally efficient without majorly compromising accuracy. YOLOv11 also works flawlessly on NVIDIA GPUs, the hardware used for this study.

To run the YOLO model on the footage, a Python based script was developed where vehicles would be each given an ID and counted when it crossed a demarcated line on the video. This line was drawn differently for each video by choosing specific x and y values denoting the line's beginning and end. For the purpose of this study the classes 'Cars', 'Trucks', 'Buses', 'Motorcycles' and 'Bicycles' were chosen. Since the COCO dataset on which YOLOv11 is trained on does not have a 3-wheeler category, the auto rickshaws recorded were categorised under the 'Cars' class observed during processing, later separated by calculating ratios. Data of both the main expressway and service lanes were collected but only the figures obtained of the access-controlled sections were used to maintain consistency with projections made by NHAI. To do so, the total figures recorded were divided by total number of lanes and multiplied by four i.e. the number of lanes in the access-controlled section.

$$T_i = (\text{Total Traffic Count} / \text{Number of Lanes Observed}) * 4$$

where,

T_i = Traffic Count on access-controlled section

Table 1: PCU factors for each class

Class	PCU factor
4-Wheelers	1.0
Motorcycles	0.5
3-Wheelers	1.0
Trucks	3.0
Buses	3.0
Bicycles	0.5

Note: Table adapted from Consultancy services for project preparation for converting dual highway from km 14.3 to km 42.0 of NH-8 (Delhi-Gurgaon section) into an access-controlled highway (National Highways Authority of India & RITES, 2001)^[14]

This value was then multiplied by the classes' respective PCU factor as determined by NHAI in their original detailed project reports (RITES Ltd. & NHAI, 2001)^[14] given in Table 1. The resultant data became the hourly PCU values of each survey location of each direction in morning peak hours and afternoon off-peak hours. To compare these values to their projected figures, a daily average PCU flow of each location was to be determined. To obtain figures for the whole day from hourly peak and off-peak values, the values of each location (both directions) were multiplied by the number of hours such a period exists during the day, mentioned in Table 2. For the sake of accuracy, a third period of 'Minimal Traffic Flow' was created equating to 0.5x the traffic seen during off-peak hours imitating midnight usage of the expressways. The time periods chosen for peak and off-peak hours represent the densely populated area of Delhi and Gurgaon where evening rush hours can last up to 10pm at night from common observation.

Table 2: Breakdown of PCU/day calculation

Traffic period name	Traffic period duration	Hours
Morning peak hour	0700 - 1100	4
Afternoon off-peak hour	1100 - 1700	6
Evening peak hour	1700 - 2200	5
Night off-peak hour	2200- 0000	2
Midnight minimal traffic flow (0.5x off-peak values)	0000 - 0700	7
Total hours	24	

$$\text{Daily Average PCU count} = \alpha i + \beta j + 0.5\beta k$$

where,

α = peak hour PCU count of location (both directions)

β = Off-peak hour PCU count of location (both directions)

i = Number of peak hours

j = Number of Off-peak hours

k = Number of minimal traffic flow hours

4.2 Calculating deviations from counterfactual values in both time periods

The next step is creating the projected traffic values for 2025 using growth rates and estimates provided by NHAI in their official project reports. These projected values act as the counterfactual baselines, which denote the traffic on Delhi-Gurgaon Expressway if Dwarka Expressway did not exist, as no provisions were made for this new expressway while the calculations were done. Counterfactual modelling has been used instead of taking another expressway as a control group or simply using Delhi-Gurgaon Expressway's real PCU figures due to time constraints and lack of necessary data. A counterfactual or baseline has also been used for Dwarka Expressway to simply observe whether traffic growth has been above or below the expected values.

Table 3: 2025 Projected PCU values for Delhi-Gurgaon Expressway and Dwarka Expressway

Delhi-Gurgaon Expressway (Access-Controlled)	
Projected Car PCU	Projected Total PCU
137,042	457,447
Dwarka Expressway Dwarka (Delhi) Section (Access Controlled)	
Projected Car PCU	Projected Total PCU
53,553	71,602
Dwarka Expressway Bharatal (Delhi) Section (Access Controlled)	
Projected Car PCU	Projected Total PCU
74,837	103,940
Dwarka Expressway Gurgaon Section (Access Controlled)	
Projected Car PCU	Projected Total PCU
49,155	68,271

Note: Table adapted from Draft feasibility report including schedules to the concession agreement: Dwarka Expressway (NH 248-BB) (National Highways Authority of India & AECOM, 2017) ^[13] and Consultancy services for project preparation for converting dual highway from km 14.3 to km 42.0 of NH-8 (Delhi-Gurgaon section) into an access-controlled highway (National Highways Authority of India & RITES, 2001) ^[14]

The counterfactual Car PCU and Total PCU values for Delhi-Gurgaon Expressway, mentioned in Table 3 were estimated by NHAI in their project report, given till the year 2023 (from

2000). However, since Covid-19 from 2020-2021 led to complete travel restrictions, the values from those years and the growth witnessed would not represent the real situation. Therefore, the projected values of 2020 and 2021 have been adjusted to 2022 and 2023, allowing the values of 2022 and 2023 to act as substitutes till 2025. We assume traffic growth during 2020-21 remained 0 (if not negative) and continued to rise again from 2022. For Dwarka Expressway, projections are decadal starting from 2017, 2020, 2025, 2030 and so on. Total PCU flow projections were given and Car PCU flows were calculated on the basis of that. A ratio of number of cars per total vehicular flow was calculated from the traffic survey values given in the project report, which was multiplied to the total decadal projections yielding us the projected values for Car PCU flow for 2025.

Actual values of Car PCUs and Total PCUs for Aug-Sept and Dec-Jan period are then subtracted from the projected values leading to the deviations. Deviations below projected figures indicate deviation of traffic from Delhi-Gurgaon Expressway or underperformance of the expressway, in the case of Dwarka Expressway. Vice versa, positive deviations represent an overburdened Delhi-Gurgaon expressway or above-expected performance on the Dwarka Expressway. Since traffic figures were collected at five different locations, three counterfactual analyses have been performed:

- 1) Comparing traffic in Delhi-Gurgaon Expressway's Delhi section and Dwarka Expressway's Dwarka (Delhi) section to their respective counterfactuals
- 2) Comparing traffic in Delhi-Gurgaon Expressway's Delhi section and Dwarka Expressway's Bharatal (Delhi) section to their respective counterfactuals
- 3) Comparing traffic in Delhi-Gurgaon Expressway's Gurgaon section and Dwarka Expressway's Gurgaon section to their respective counterfactuals

The three different analyses allow us to better understand if Dwarka Expressway has led to traffic deviation in any of the three locations. Counterfactuals exist for each of the three survey points on Dwarka Expressway; however, a common counterfactual has been used for both Delhi-Gurgaon Expressway survey locations as Gurgaon's projection was made on the outskirts of the city, which will be an inappropriate estimate for the study. Based on deviations from projected traffic volumes, a complete difference-in-differences analysis is performed to assess how traffic on the Delhi-Gurgaon Expressway changed relative to the growth observed on the Dwarka Expressway after its opening, allowing for a comparative evaluation of traffic redistribution and induced demand across the two corridors.

Calculation for Difference-in-Differences:

$$\Delta\alpha = \Delta\alpha_1 - \Delta\alpha_0$$

$$\Delta\beta = \Delta\beta_1 - \Delta\beta_0$$

$$\text{DiD} = \Delta\alpha - \Delta\beta$$

where,

$\Delta\alpha$ = Total deviation on Delhi-Gurgaon Expressway

$\Delta\beta$ = Total deviation on Dwarka Expressway

ΔX_1 = Deviation from projection in Dec-Jan period

ΔX_0 = Deviation from projection in Aug-Sept period (X is either α or β)

5. Results and Discussion

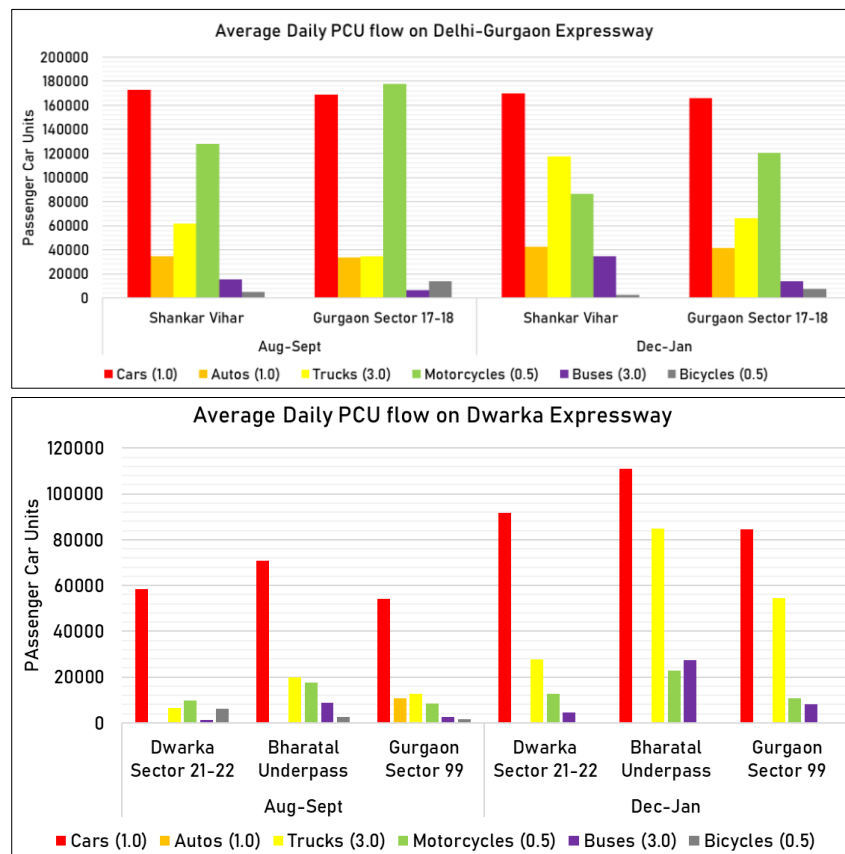


Figure 5: Observed daily PCU flow on both expressways in Aug-Sept and Dec-Jan

The total PCU flow and its constituents for Delhi-Gurgaon Expressway and Dwarka Expressway in Aug-Sept and Dec-Jan have been depicted through a barchart in Figure 5. For the Aug-Sept data, a 20% upward correction has been performed on Delhi-Gurgaon Expressway's data in each category of vehicles to override any effect on traffic due to monsoon water-logging, a severe problem seen on the expressway (Sachdev, 2025; Yasmoon & Saud, 2025) [18, 24]. On both expressways, cars hold the highest share of PCU movement, surpassed by motorcycles only at Gurgaon Sector 17-18 in

Aug-Sept on the Delhi-Gurgaon Expressway. Total flow on Delhi-Gurgaon Expressway rises from 417,908 PCUs/day to 453,971 PCUs/day in Delhi whereas it falls from 435,460 PCUs to 415,475 PCUs in Gurgaon from Aug-Sept to Dec-Jan. On Dwarka Expressway, total PCU count rises sharply in all three survey locations, going from 82,393 PCUs/day in Dwarka, 119,589 PCUs/day in Bharatal and 90,160 PCUs/day in Gurgaon Sector 99 to 136,624 PCUs/day, 246,152 PCUs/day and 158,154 PCUs/day respectively in Dec-Jan.

5.1 Deviations and difference in difference analyses

Table 4: Deviations and difference-in-differences

i) Deviations from Projection (Actual - Projection)	Deviations on NH-48 (Delhi Section)		Deviations on NH-244BB (Dwarka-Delhi Section)	
	Cars	Total	Cars	Total
Aug-Sept	+35,993	-39,539	-20	+10,791
Dec-Jan	+32,914	-3,476	+38,124	+65,022
Difference-in-Differences for Total PCUs	[(-3,476) - (-39,539)] - (65,022 - 10,791) = -18,168			
Difference-in-Differences for Car PCUs	(32,914 - 35,993) - [38,124 - (-20)] = -41,223			
ii) Deviations from Projection (Actual - Projection)	Deviations on NH-48 (Delhi Section)		Deviations on NH-244BB (Bharatal-Delhi Section)	
	Cars	Total	Cars	Total
Aug-Sept	+35,993	-39,539	-3,976	+15,649
Dec-Jan	+32,914	-3,476	+36,148	+142,212
Difference-in-Differences (Total PCUs)	[(-3,476) - (-39,539)] - (142,212 - 15,649) = -90,500			
Difference-in-Differences (Car PCUs)	(32,914 - 35,993) - [36,148 - (-3,976)] = -43,203			
iii) Deviations from Projection (Actual - Projection)	Deviations on NH-48 (Gurgaon Section)		Deviations on NH-244BB (Gurgaon Section)	
	Cars	Total	Cars	Total
Aug-Sept	+31,988	-21,987	+4,874	+21,889
Dec-Jan	+28,980	-41,972	+35,467	+89,883
Difference-in-Differences (Total PCUs)	[(-41,972) - (-21,987)] - (89,883 - 21,889) = -87,979			
Difference-in-Differences (Car PCUs)	(28,980 - 31,988) - (35,467 - 4,874) = -33,601			

Table 4 shows the deviations from projections for Car PCU and Total PCU flow through the scenarios that were created. In (i) Cars on Delhi-Gurgaon Expressway are vastly above the projection and show minimal decrease of 3,000 PCUs after opening of Dwarka Expressway. The total PCU projection falls sharply below projected values in Aug-Sept whereas the gap closes in Dec-Jan indicating an increase in traffic rather than decrease, mostly through growth in buses and trucks. On Dwarka Expressway, Car PCU sharply increases from Aug-Sept to Dec-Jan however without a significant decrease on Delhi-Gurgaon Expressway showing that mostly induced demand was catered to. Total PCU count explodes but without any relief on Delhi-Gurgaon Expressway. (i)'s DiD comes to be -18,168 for total PCU flow deviation and -41,223 for Car PCU flow deviation indicating that cars responded more strongly to the new expressway than overall traffic, indicating higher route-switching elasticity for private vehicles. However, no concrete congestion relief or diversion from Delhi-Gurgaon Expressway was observed.

In (ii) Cars on Delhi-Gurgaon Expressway are vastly above the projection and show minimal decline after the inauguration like (i). The total PCU projection falls sharply below projected values in Aug-Sept whereas the gap closes in Dec-Jan indicating an increase in traffic rather than decrease, also like (i). On the Bharatal section, initially cars are less than the projection but shoots up sharply by December-January accounting for mostly induced demand. Total PCU demand on Dwarka Expressway remained above projection indicating heavy vehicle growth and new trips being added. The DiD values are -90,500 and -43,203 respectively showing a substantial post-opening redistribution of traffic from the Delhi-Gurgaon Expressway to the Dwarka Expressway. While absolute traffic volumes on the Delhi-Gurgaon Expressway did not decline, its growth significantly underperformed relative to projections when compared to the rapid growth observed on the new corridor. The larger magnitude of total PCU DiD suggests system-wide diversion, while the negative Car PCU DiD confirms that private vehicle users were more responsive to the new capacity. This outcome is consistent with corridor substitution combined with induced demand on the Dwarka Expressway rather than pure congestion elimination.

In the last case of Gurgaon sections of both expressways, Car PCUs declined by 3,000 and total PCUs by almost 20,000 on the Delhi-Gurgaon Expressway. Dwarka Expressway sees a massive growth of about 31,000 Car PCUs and 67,000 PCUs in total. Thus, a significant deviation of trucks and buses, which can also be seen from Figure 4. PCUs are seen in this part of the expressway. A Difference-in-Differences value of -87,979 PCUs for total flow indicates that, following the opening of the Dwarka Expressway, traffic on NH-48 fell substantially below projected levels while traffic on NH-244BB rose substantially above projections. The negative DiD and individual deviation analysis reflects a post-opening divergence in heavy vehicles along with allowing induced demand to act.

6. Conclusion

DiD analysis and deviation comparisons through three different counterfactual analyses has shown that substantial congestion relief on the Delhi-Gurgaon Expressway has only occurred in the Gurgaon section for heavy vehicles. Car PCU values remain unaffected with very minimal decreases and

Dwarka Expressway mostly catering to new trips being generated from Najafgarh, Dwarka, Palam Vihar, Gurgaon sectors 90-120 etc.

The Land Use and Land Cover (LULC) change analysis carried out for the study area further supports a causal relationship between the observed changes on NH-48 and the inauguration of the Dwarka Expressway. No new road networks or major development activities were recorded within the study period, strengthening the attribution of observed traffic changes to the opening of the expressway. This absence of parallel infrastructural or land development interventions reinforces the validity of the findings and confirms that the changes in traffic dynamics along NH-48 are a direct consequence of the Dwarka Expressway becoming operational.

7. Limitations of the study

Due to the absence of comprehensive and reliable recorded traffic data for the Delhi-Gurgaon Expressway, the study relies on projected traffic volumes provided by NHA. While these projections are based on systematic modelling and incorporate anticipated future growth, the availability of ground-level traffic data at a finer, more disaggregated level would have significantly strengthened the analysis. Such data would have enabled more precise estimation of deviation values and allowed the analysis to be extended to additional vehicle categories, including trucks, buses, and motorcycles, which could not be examined in the present study. Similarly, frequent data points rather than a six-month gap will also improve the validity and reliability of the results discussed. The study also uses the projected figures as the counterfactual instead of a control expressway due to lack of available data which can be improved upon, strengthening causal inference.

8. Conflict of interests

The author whose name is listed certifies that they have NO affiliation with or involvement with any organisation or entity with any financial interest (such as grants or employment) or non-financial interest (such as personal relationship or affiliation) in the subject matter or materials discussed in this manuscript.

References

1. Bakirci M. Utilizing YOLOv8 for enhanced traffic monitoring in intelligent transportation systems (ITS) applications. *Digit Signal Process.* 2024;152:104594. DOI:10.1016/j.dsp.2024.104594.
2. Chandra S, Gangopadhyay S, Velmurugan S, Ravinder K. *Indian highway capacity manual (Indo-HCM)*. New Delhi: Central Road Research Institute; 2017.
3. Das AK. Delhi-Gurgaon highway: Road to nowhere. *The Times of India*; 2003 Mar 13. Available from: <https://timesofindia.indiatimes.com/delhi-times/delhi-gurgaon-highway-road-to-nowhere/articleshow/40106061.cms>
4. Delhi Development Authority. *Draft land use plan for Delhi 2041*. 1st ed. New Delhi: Delhi Development Authority; 2021.
5. Department of Revenue & Disaster Management, Government of Haryana. *Flood control order: District Gurugram*. Chandigarh: Government of Haryana; 2021.
6. Dutta A. PM's office may step in to resolve delays in Dwarka Expressway project. *Hindustan Times*; 2018 Nov 20. Available from: <https://www.hindustantimes.com/delhi-news/pm-s-office-may-step-in-to-resolve-delays-in-dwarka->

- expressway-project/story-4YcA59KRlOmL0Nw5Gb3FrN.htm
7. Garg S, Mahapatra D. Opportunism galore: The case of Delhi-Gurgaon Super Connectivity Limited. In: Akintoye A, Beck M, Kumaraswamy M, editors. The Emerald handbook of public-private partnerships in developing and emerging economies. Bingley: Emerald Publishing; c2017. p. 489-512. DOI:10.1108/978-1-78714-493-420171018.
 8. GeoFabrik. OpenStreetMap data for Northern Zone, India. Karlsruhe: GeoFabrik; 2026. Available from: <https://download.geofabrik.de/asia/india/northern-zone.html>
 9. Goldstein SR. Planning the millennium city: The politics of place-making in Gurgaon, India. *Int Area Stud Rev.* 2016;19(1):12-27. DOI:10.1177/2233865916628798.
 10. Kumar A. Delay in work on Northern Peripheral Road adds to commuter's woes on Delhi-Gurgaon expressway. *India Today.* 2012 Oct 3. Available from: <https://www.indiatoday.in/india/north/story/delhi-gurgaon-expressway-northern-peripheral-road-delay-commuter-woes-117611-2012-10-02>
 11. Kunekar P, Narule Y, Mahajan R, Mandlapure S, Mehendale E, Meshram Y. Traffic management system using YOLO algorithm. *Eng Proc.* 2023;59(1):210. DOI:10.3390/engproc2023059210.
 12. Kurle S, Behara KN, Prasad JR, Arkatkar S, Sarkar AK. Study of lane utilization on Delhi-Gurgaon Expressway. *Transp Res Procedia.* 2016;17:674-684. DOI:10.1016/j.trpro.2016.11.122.
 13. National Highways Authority of India, AECOM. Draft feasibility report including schedules to the concession agreement: Dwarka Expressway (NH 248-BB). New Delhi: National Highways Authority of India; 2017.
 14. National Highways Authority of India, RITES. Consultancy services for project preparation for converting dual highway from km 14.3 to km 42.0 of NH-8 (Delhi-Gurgaon section) into an access-controlled highway. New Delhi: National Highways Authority of India; 2001.
 15. Pathak AN, Pardeep, Yusuf, Kumar N. Traffic and volume study of Gurugram, Haryana. *Int J Manag IT Eng.* 2020;10(5).
 16. Puvvala R, Ponnu B, Arkatkar S, Velmurugan S. Estimating capacity for eight-lane divided urban expressway under mixed-traffic conditions using computer simulation. *Int J Adv Eng Sci Appl Math.* 2013;5(2-3):177-194. DOI:10.1007/s12572-013-0089-z.
 17. Rajagopalan S, Tabarrok AT. Lessons from Gurgaon, India's private city. Research Paper No. 14-32. Fairfax (VA): George Mason University, Department of Economics; 2014 Oct 24. DOI:10.2139/ssrn.2514652.
 18. Sachdev A. Gurugram: Massive traffic jam stalls Delhi suburb as rains wreak havoc. *BBC News;* 2025 Sep 2. Available from: <https://www.bbc.com/news/articles/c5yeyg5n08jo>
 19. Saxena A, Choudhury B. Internalising the externalities of urban private transport: A case of Gurugram, National Capital Region, India. *Case Stud Transp Policy.* 2022;10(3):1885-1897. DOI:10.1016/j.cstp.2022.08.002.
 20. Singh R. Gurgaon expressway: A project gone haywire. *The Economic Times;* 2010 Aug 27. Available from: <https://economictimes.indiatimes.com/news/economy/infrastructure/gurgaon-expressway-a-project-gone-haywire/articleshow/6442946.cms>
 21. Som V. NDTV report: Can Dwarka Expressway end Delhi-Gurugram traffic nightmares? NDTV. 2025 Aug 19. Available from: <https://www.ndtv.com/india-news/ndtv-report-can-dwarka-expressway-end-delhi-gurugram-traffic-nightmares-9113520>
 22. Ultralytics. Ultralytics YOLO11. Ultralytics YOLO Docs; 2026 Jan 20. Available from: <https://docs.ultralytics.com/models/yolo11/>
 23. U.S. Geological Survey. Landsat 9 Level-2 data. Reston (VA): U.S. Geological Survey; 2026. Available from: <https://www.usgs.gov/landsat-missions/landsat-9>
 24. Yasmoon Z, Saud A. Urban flood disasters and mitigation practices: Cases of Srinagar, Gurugram and Chennai; 2025. Available from: <https://www.academia.edu/33585369>