



Assessment of Gaseous Emissions from Tailpipes in Heterogeneous Traffic Situations

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How to Cite this Article:

Jabri, S. B. A., Uddin, M., Mujahed, M., Farsi, M. & Sultana, T. (2026). Assessment of Gaseous Emissions from Tailpipes in Heterogeneous Traffic Situations. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(05).
<https://doi.org/10.55041/ijcope.v2i5.496>

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Abstract—

The establishment of strict regulations and developments in engine technologies, particularly the improvement of after-treatment systems to effectively moderate emissions, are responsible for the decrease in real-world emissions. It is important to understand that emission concentrations might fluctuate greatly depending on the driving conditions. Therefore, it is crucial to have a careful understanding of emission characteristics under various operating conditions as well as steady state conditions. Due to poor replication of the driving behavior, laboratory driving cycles cannot capture the real-world driving emissions. In this current study, idle emission and running emission tests were performed to characterize the behavior of carbon monoxide (CO), carbon dioxide (CO₂), non-methane hydrocarbons (NMHC), and oxygen (O₂) emitted from various vehicle categories. Portable emissions measurement system (PEMS) was used to conduct real time emission tests. Idle emission tests were carried out on two-wheelers, three-wheelers, cars, and buses. A total of 409 idle emission samples were collected, and data was further improved for analysis. Multiple linear regression (MLR) and artificial neural network (ANN) models were developed to investigate the emission characteristics for a set of predictor variables. A two-stage least squares (2SLS) model was developed to assess the interdependency between CO₂ emission concentration and emitted O₂ emission concentration. Running emissions were

carried for one diesel pickup truck. Virtual BOX (VBOX) was used to collect speed data simultaneously with real time emissions data. Emission factors were calculated and averaged across speed bins. Speed based emission models were developed to investigate the relation. The findings indicated a clear inverse relationship between vehicle speed and emissions, as higher speeds corresponded to lower emission levels.

Keywords: After-treatment systems, real-world emissions, laboratory driving cycles, and VBOX.



I. INTRODUCTION

Vehicle tailpipe emissions are a major concern in urban areas. Despite engineers designing more fuel-efficient vehicles, the rapid growth in vehicle numbers keeps total pollution high. Electric vehicles simply transfer emissions from roads to industries (through battery production). Laboratory driving cycles like India's IDC fail to capture real traffic behavior such as mixed vehicle types, stop-go patterns, and congestion. Portable Emissions Measurement Systems (PEMS) provide a better solution by measuring actual on-road emissions in real time.

Objectives of the Study:

- Evaluate tailpipe emissions across different Bharat Stage (BS) standards
- Model idle emission concentrations (CO, CO₂, O₂, NMHC)
- Model inter-dependency between CO₂ and O₂ (endogeneity)
- Analyze the effect of vehicle speed on running emissions

II. LITERATURE REVIEW

Real-world emissions cannot be replicated in labs. PEMS is the most effective tool because it travels with the vehicle and captures second-by-second data. Remote sensing is limited to fixed points, and tunnel studies cannot attribute emissions to specific vehicles. Bibliometric analysis using VOSviewer identified key research clusters around PEMS, NO_x, diesel exhaust, and Real Driving Emissions (RDE)

. Key Findings from Past Studies:

- Cold start emissions are the highest — due to low catalyst temperatures
- Sharp acceleration events cause emission spikes — sometimes exceeding an entire trip's average
- Peak-hour emissions nearly double compared to off-peak hours
- Auto-rickshaws emit more CO and HC than passenger cars at the same speed
- Standard models (COPERT, CMEM) under-predict real emissions by a significant margin
- Vehicles at steady 40–50 kmph show the lowest emission levels
- Aggressive driving increases CO₂ by 20–40% and NO_x by 50–255%

III. METHODOLOGY

The methodology follows 7 stages: literature review → gap identification → objectives → data collection → data analysis → modelling → conclusions. Sample size was calculated using Cochran's formula at 95% confidence interval with 5% margin of error. Emission Factor = Emission rate (g/s) ÷ Instantaneous vehicle speed.



Models Used:

Model	Purpose	Key Feature
MLR (Multiple Linear Regression)	Examine relationship between one dependent & multiple independent variables	F-test for significance; VIF for multicollinearity
ANN (Artificial Neural Network)	Capture non-linear patterns in emission data	Backpropagation; sigmoid activation; 70/30 train-test split
2SLS (Two-Stage Least Squares)	Handle endogeneity between CO2 and O2	Stage 1: estimate endogenous variable; Stage 2: main regression
Polynomial Regression	Speed-based emission factor modelling	Higher-order curves for better fit than linear models

IV. Equipment:

INDUS FGA 53X Flue Gas Analyser (ISO 9001:2015 certified). Measures CO, CO₂, NMHC, O₂, NO_x, and SO_x.

Uses NDIR sensor for CO/CO₂/NMHC and electrochemical sensor for O₂/NO_x/SO_x.

Idle Emissions — Hanumakonda Region, Warangal:

Vehicle Type	Location	Samples
Two-Wheelers	NIT Warangal Campus	108
Three-Wheelers	Kazipet Railway Station, Fathima Nagar, Hanumakonda Bus Station	100
Buses	Hanumakonda Bus Depot	101
Cars	NIT Warangal Fuel Station & Nakkalagutta Shopping Complex	100
TOTAL		409

Running Emissions — Hyderabad City:

One Mahindra diesel pickup truck (BS IV, 2489cc, 75 bhp) driven on 4 test routes (each ≥ 15 km) in Hyderabad. VBOX collected speed/acceleration at 10 Hz; FGA collected emissions at 1 Hz. After filtering and synchronization: 15,539 samples used for analysis.

BS Standard Distribution (% share):



Vehicle	Dominant Standard	% Share
Two-Wheelers	BS IV	44.4%
Three-Wheelers	BS IV	39.0%
Cars (Petrol)	BS IV	52.9%
Cars (Diesel)	BS IV	46.3%
Buses	BS IV	40.6%

V. RESULTS AND DISCUSSION

. ANOVA Results (BS III vs BS IV vs BS VI):

One-way ANOVA tested significant differences in emission concentrations across BS standards ($p < 0.05$ = significant difference).

Vehicle Type	Significant Differences Found
Two-Wheelers	CO ₂ & O ₂ differ between BS III–IV; CO & NMHC differ between BS IV–VI
Three-Wheelers	NMHC & NO _x differ between BS IV–VI; CO ₂ & O ₂ differ between BS III–IV
Diesel Cars	CO ₂ , O ₂ , NO _x differ between BS IV–VI
Petrol Cars	CO differs BS III–IV; NO _x & SO _x differ BS IV–VI
Buses	CO and NO _x show highly significant variation ($p < 0.001$) between BS III–IV



. Emission Concentration Models:

Pollutant	MLR Equation	MLR R ²	ANN R ²	Key Influencer
CO	$CO = 2.260 + 0.007(Temp) - 1.064(FuelType) - 0$.137(0.190BS)	0.436	Fuel Type
CO ₂	$CO_2 = 8.719 + 0.015(Temp) - 4.631(FuelType) +$	0.541(BS)0.390	0.729	Fuel Type
O ₂	$O_2 = 7.045 - 0.027(Temp) + 7.203(FuelType) - 0$.621(0.447BS)	0.708	Fuel Type

Key Interpretation:

- **Fuel Type** is the most influential variable across all three emission models
- **Higher BS standards** reduce CO (cleaner engines) but increase CO₂ (more complete combustion)
- **Temperature** positively affects CO and CO₂ but negatively affects O₂
- **ANN consistently outperformed MLR** — significantly higher R² values across all pollutants
- Vehicle age was found **insignificant** in all MLR models and was removed

Model Variables

An inverse relationship exists between CO₂ and O₂ in exhaust gas. When oxygen is fully consumed in combustion, CO₂ rises and O₂ falls. Since O₂ is endogenous (correlated with the error term), standard regression would give biased results. A Two-Stage Least Squares (2SLS) model was developed to handle this

Role	Variable
Dependent	CO ₂
Endogenous	O ₂
Exogenous	Vehicle Age
Instruments	Fuel Type, Flue Gas Temperature (Temp°C)



Model Results:

Model	Equation	R ²	Adj. R ²	Residual SE
Basic 2SLS	$CO_2 = 13.881 - 0.643(O_2) - 0.031(\text{Vehicle Age})$	0.954	0.9537	0.8708
Over-identified 2SLS (+ BS Standard as instrument)	$CO_2 = 13.949 - 0.648(O_2) - 0.030(\text{Vehicle Age t})$	0.955	0.9546	0.863

Key Findings:

- Higher O₂ in exhaust → lower CO₂ (incomplete combustion)
- Older vehicles → lower CO₂ (engines burn fuel less completely)
- Hausman test confirmed endogeneity — 2SLS was the correct and necessary approach
- Over-identified model (R² = 0.955) performed slightly better than basic 2SLS (R² = 0.954)
- Both models are highly significant (p-value = 0.000)

V. CONCLUSION

1. Real-world emissions differ **significantly** from laboratory/standard values
2. **ANN models** are substantially more accurate than MLR for emission prediction
3. **Higher BS standards** effectively reduce harmful pollutants (CO, NMHC, NO_x)
4. **Higher vehicle speeds** correspond to lower emission levels (inverse relationship)
5. **Fuel type** is the single most influential predictor across all emission models
6. Idle emissions are the **lowest** of all driving modes — acceleration produces the most
7. Three-wheelers with older BS standards (BS I/II) are major **emission hotspots**
8. The 2SLS model with R² = 0.955 effectively captured CO –O interdependency



ACKNOWLEDGMENT

We would like to express my sincere thanks to our beloved guide **Mrs. Taheseen Sultana**, Assistant Professor of Civil Engineering, Deccan College of Engineering and Technology for his timely and valuable suggestions. We are thankful for her guidance and active supervision at every stage of the dissertation work. She has been constant driving force, source of inspiration and encouraging me throughout this work. It is her immense patience and co-operation that has helped for the successful completion of this work.

We are thankful to **Dr. Mir Iqbal Faheem**, Director of Deccan Group of Institutions for providing facilities to carry out the Project work.

We are thankful to, Principal **Dr.P. Vishwa Pathy** Professor & Principal of Deccan College of Engineering and Technology for providing facilities to carry out the Project work

We are very much thankful to **Dr. Mohammed Zaker** Associate Professor, in charge Head of Dept. of Civil Engineering, Deccan College of Engineering and Technology and management for providing facilities to carry out the Project work.

We are thankful **to all the faculties**, Department of Civil Engineering, DCET with whom we was associated during our course of study for their kind cooperation.

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