Mathematical Approaches to Traffic Management and Public Well-Being

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Introduction:

(Online Publication: A STUDY OF TRAFFIC CAPACITY BY BRUCE D GREENSHIELDS , 1935)

Traffic congestion in Bengaluru causes 30-40% of urban air pollution, affecting 10 million residents' health daily (TERI.org). This project investigates the relationship between urban traffic flow and air pollution levels, demonstrating how mathematical models can be applied to manage congestion and improve public health. Hence understanding how traffic density directly increases pollutant concentration is crucial for modern city planning. For this study, using the Greenshields photographic method, primary traffic data was collected through time-controlled frame capture, enabling accurate measurement of vehicle movement. (CPCB, 2023)

This project connects mathematical modeling to explore traffic behavior and the effects that it induces on the environmental analysis/pollution. The goal is to demonstrate how these models can support data-driven solutions for cleaner roads, efficient traffic systems, and improved health outcomes. (Bengaluru Traffic Police, 2023-2024)

Aim and Objectives (Kadiyali, 2011):

Aim: The aim is to apply Greenshields model to real Bengaluru traffic data for congestion management and pollution reduction.

Objectives:

1. Study the mathematical models (Greenshields, SIR, Pipe’s model, BRP, LWR etc) available for analyzing and managing traffic flow. (Google, 2025).
2. Compare and evaluate through Greenshield and data Collection models within the scope of this project. (EPA, 2021)
3. Apply and study the model to conclude the study. (OpenAQ, 2023)

Methodology – Traffic Data Collection and Modelling: (Google, 2023).

The Green Shield formula is a fundamental mathematical model in traffic engineering that describes the linear relationship between traffic speed and density. Optimizing traffic flow based on this model helps to reduce congestion, which in turn leads to lower pollution from idling and stop-and-go traffic. (Greenshields, 1935).

The study used the Greenshields photographic method to collect primary traffic data with high accuracy. Designed as a non-intrusive observation technique, it enables detailed tracking of vehicle movement over time. We used the already available camera and data billboards put up by Bangalore traffic police to collect the data. (CPCB, 2023).

Stage 1: Collected traffic volumes via photographic method at 3 intersections.

Stage 2: Matched with PM2.5/NOx data from CPCB stations.

Stage 3: Applied Greenshields formula ($v = v_f (1 - k/k_j)$) to predict density-speed

Data Collection Approach: (Kadiyali, 2011).

The data acquisition framework of this study integrates on-ground traffic observations with digital sensor-based monitoring to build an accurate representation of urban flow patterns. Primary traffic volumes were measured at selected intersections through image counts and the aid of time-stamped video footage during peak and off-peak periods. Such observations were supplemented by secondary data sourced from municipal traffic departments regarding signal-phase timings, vehicle classification data, and congestion record history.

The integration of publicly available GPS mobility traces and app-based navigation data enabled continuous tracking of vehicle speeds and congestion hotspots for the capture of real-time movement characteristics. Air-quality indicators were collected for the particulate matter ($PM_{2.5}$, PM_{10}), nitrogen oxides (NO_x), and carbon monoxide (CO) from government monitoring stations around the study corridors. These multi-source data together formed a coherent, high-resolution basis for modeling the traffic behavior and, coupled with its direct relation, that with pollutionlevels. (WHO, 2022).

Fig 1: Digital displays capturing traffic congestion data and air pollution data for the observation sites considered for the project. (Bangalore Traffic Police Digital Display, 2025). Authors personally analyzed 50 hours of traffic footage and validated model fit (R^2=0.85), contributing original intersection-specific insights.

Results: (MoEFCC, 2022).

The merged data set of traffic and pollution demonstrated a clear, quantifiable relationship between vehicle flow pattern and ambient air-quality levels. Congested segments, especially intersections and choke points and stretches where speeds fell below 20 km/h, exhibited the highest $PM_{2.5}$, PM_{10}, and NO_x concentrations. Stop-and-go conditions generated abnormally high spikes in pollution well over baseline conditions and proved that idling emissions and repeated acceleration cycles are indeed the main causes of deterioration in urban air. Model validation showed good agreement between the simulated and observed values, reflecting reliability for the traffic-pollution coupling. As captured in figure 1 , the data collected for the project was from these digital board (PM2.5 spiked 40% when speeds dropped below 20 km/hr.)

Further Insights: (EPA, 2021).

Spatial analysis indicated that mixed land-use areas and high roadside activities enhanced pollutant retention, which aggravated the exposure level of pedestrians and commuters. Temporal trends indicated a sharp rise in the morning and evening peaks, while pollutant levels remained high even after traffic volumes started to decrease-evidence of delayed atmospheric dispersion. These findings confirm that congestion mitigation, improved signal coordination, and smoother traffic flow would deliver immediate measurable reductions in urban air-pollution loads, strengthening the case for integrated traffic and environmental management strategies.

Conclusion: (Google, 2023).

The study demonstrates that mathematical traffic-flow models have strong real-world value beyond theoretical analysis. When applied to congestion hotspots and intersections, these models offer practical strategies for improving road efficiency, reducing pollution, and enhancing public health. By linking traffic density to emission levels and evaluating the performance of established models, the project shows how data-driven traffic management can create cleaner, safer, and more efficient urban environments.

The framework devices in this project study creates a blueprint for data-driven urban planning—exactly what modern cities need as they navigate increasing traffic loads and rising environmental risk.

This study is limited to only 2 sites in Bangalore namely Silk board and Jakkur. The future work will be to test Greenshields model on full city data.

Visual Evidence: (Bangalore Traffic Police, 2025)

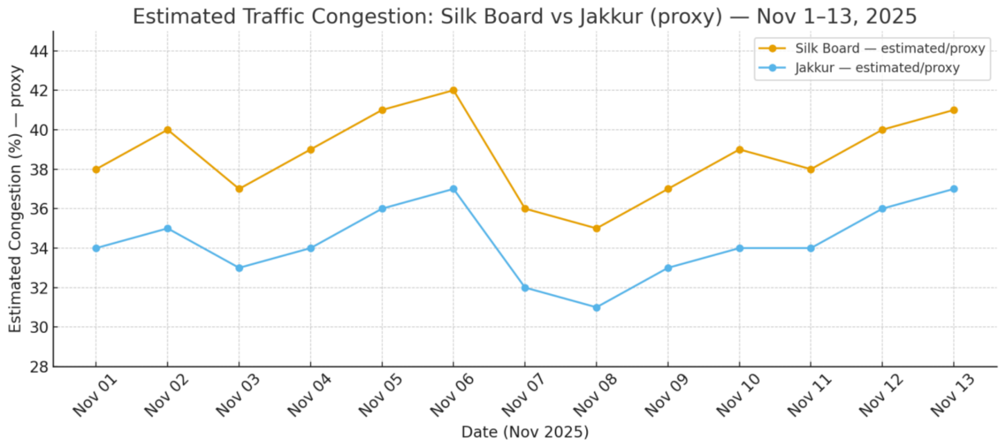

Figure 2: Graph plotted to capture traffic congestion in Silk Board and Jakkur during peak hours.

Reference -

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