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Comprehensive Analysis of Taxi Service Distribution, Demand Hot spots, and Air Pollution Impact: A GIS and Big Data Approach

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Abstract. As urban transportation demand increases, optimizing taxi services is critical for improving traffic flow and reducing environmental impact. This study investigates the spatial distribution of taxi services, demand hotspots, and their relation to air pollution using Geographic Information Systems (GIS), big data, and land use analysis. After collecting and processing taxi GPS data, we identified high-demand areas such as airports and commercial centers. We then overlaid this data with air pollution monitoring information to analyze potential correlations. The analysis revealed significant overlaps between regions of frequent taxi operation and elevated pollution levels. Using spatio-temporal models, we predicted demand patterns across different periods and explored the connection between land use (commercial, residential, and industrial zones) and traffic congestion. The results show that taxi services contribute significantly to air quality deterioration in densely populated and commercially active areas. These findings suggest that optimized taxi dispatch and fleet redistribution strategies could not only enhance operational efficiency but also alleviate air pollution in urban centers. This study provides actionable insights for policymakers and taxi companies to develop data-driven approaches to urban transportation management, reducing air pollution while improving service efficiency.

Keywords: taxi service distribution, demand hot spots, air pollution.

1. Introduction

In rapidly urbanizing cities, the efficiency of transportation systems plays an important role in both economic development and environmental sustainability.[1] Taxi services, as an essential part of urban mobility, are often concentrated in high-demand areas, creating a direct link between traffic congestion and air quality.[2] Although there are plenty of researches on taxi service optimization, few have thoroughly explored its connection with air pollution.

After researching for some other papers, it is obvious to find that people focus more on taxi demand or how to use the taxi system more effectively. However, the environmental impacts of taxi operations, particularly in relation to air pollution, have not been fully explored in many urban studies. Understanding the spatial distribution of taxi services and how it correlates with air pollution hot spots can provide critical insights for city planners and environmental managers. So this paper puts more attention on the relationships between air pollution and taxi distribution.

The integration of Geographic Information Systems (GIS), big data, and land use analysis offers a powerful framework for examining these issues. By leveraging GPS data from taxi services, combined with air pollution monitoring data and land use information, we can uncover patterns of high taxi usage in areas suffering from poor air quality. These patterns are often influenced by the underlying land use, such as dense commercial districts or transportation hubs, where both taxi demand and pollution levels are typically elevated. This study aims to conduct a comprehensive analysis of the spatial distribution of taxi services, demand hot spots, and their environmental impacts, particularly focusing on air pollution. Through GIS-based spatial analysis and predictive modeling using R language, this research will explore how taxi operations contribute to air pollution in urban environments. Furthermore, by examining the role of land use in shaping these patterns, the study seeks to propose optimization strategies for taxi operations that could reduce congestion, improve service efficiency, and mitigate the negative impacts on air quality.

This research will provide valuable insights into urban transportation management and environmental protection, supporting the development of sustainable traffic and environmental policies in the context of smart city initiatives. The core questions of this study include: 1) Is there a significant overlap between the spatial distribution of taxi services and air pollution hot spots? 2) Do different land use types (such as commercial, residential, and industrial areas) influence the relationship between taxi services and air pollution? 3) Can urban air pollution be effectively reduced through optimizing taxi dispatch and fleet distribution?

2. Method

2.1. Data Collection and Processing

This study employs GIS technology and R programming, combined with big data analysis, to comprehensively analyze taxi service data, air pollution data, and land use data in New York City. [3]The research unfolds through several key steps.

This study use First, taxi trip data from New York City, including pick-up and drop-off locations, trip times, and distances, is collected and processed. [4]Using this data and GIS techniques, the spatial distribution of taxi services is analyzed, and hotspot maps of high-demand areas are generated. [5]Then, air pollution data from monitoring stations is utilized to analyze the distribution of pollutants (such as PM2.5 and NO2) and to identify regions with high levels of air pollution. To ensure the validity and reliability of the data, this study has strictly screened all kinds of data sources in the data collection stage. Taxi data covered multiple years, and the data were denoised by R language to eliminate outliers. Meanwhile, for air pollution data, various interpolation methods were used to fill in the missing values in the monitoring station data. After data processing, all data were integrated into a uniform format to ensure compatibility between different data sets. This step is the basis for subsequent analyses aimed at improving the accuracy of model predictions.

2.2. Spatial Distribution and Overlay Analysis

Next,This study spatial overlay analysis is conducted to examine the relationship between taxi service hotspots and air pollution hotspots. This process identifies areas where high-frequency taxi service overlaps with areas experiencing severe air pollution, revealing the interplay between urban traffic flow and environmental pollution. In using GIS technology for spatial distribution analysis, the study pinpoints the peak areas of taxi demand within the city by constructing a hotspot analysis model. These areas not only reflect the travelling demand of passengers, but also indirectly indicate the economic activity of different areas of the city. In addition, a spatial dispersion map of pollutants was generated by combining the data from the air pollution monitoring points to show the distribution pattern of pollution within the city. This step of the analysis helps to identify potential relationships between urban transport and air pollution, laying the foundation for subsequent overlay analyses .The spatial superposition analysis is not limited to simply overlapping taxi services and air pollution hotspots, but also calculates the correlation between the density of taxi services and pollutant concentrations in different areas by introducing a weighting analysis method. This integrated analysis identifies specific areas where pollution levels are relatively low despite high taxi activity, suggesting that the area may

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have better ventilation conditions or better urban planning design. In addition, such analyses help urban planners to gain a deeper understanding of the dual impacts of traffic and the environment, and provide a basis for decision-making on future urban transformation.

2.3. Optimization Strategies Based on Land Use

Combining land use data, this study further analysed the relationship between taxi services and air pollution in different types of areas (e.g., commercial, residential, industrial). The analyses found that commercial districts are usually hotspots for taxi services, but the level of air pollution varies according to the differences in traffic congestion and building layouts. By comparing the various types of areas, the study not only reveals the interaction between different land types and traffic flows, but also proposes traffic optimisation suggestions for different functional areas with the aim of reducing environmental pollution. The study also incorporates land use data to assess how different land types (such as commercial, residential, and industrial zones) influence the relationship between taxi services and air pollution. By overlaying land use data with taxi and pollution data, the interaction between traffic activity and environmental issues in various urban zones is evaluated.

Finally, based on these analyses, strategies for optimizing taxi dispatch and fleet distribution are developed. The study explores how optimizing taxi routes could potentially reduce air pollution. Through simulations of different dispatching scenarios, the research investigates how to minimize idle taxi trips and reduce their impact on air quality, providing recommendations for urban traffic management and environmental governance.

This methodology provides a comprehensive evaluation of the relationship between taxi services and air pollution and offers strategies for mitigating urban air pollution through factors such as land use and traffic flow.

3. Results

3.1. Taxi Service Distribution and Demand Hotspots

By analyzing taxi GPS data, we found that taxi services in New York City are highly concentrated in areas such as Manhattan, Times Square, Wall Street, and Central Park. These areas are not only the centers of commerce and tourism but also the regions with the most severe traffic congestion and air pollution. The demand hotspots are mainly concentrated in the city's commercial centers, tourist attractions, and densely populated residential areas. Especially during rush hours, the significant increase in traffic flow drives the demand for taxis, further exacerbating traffic congestion.

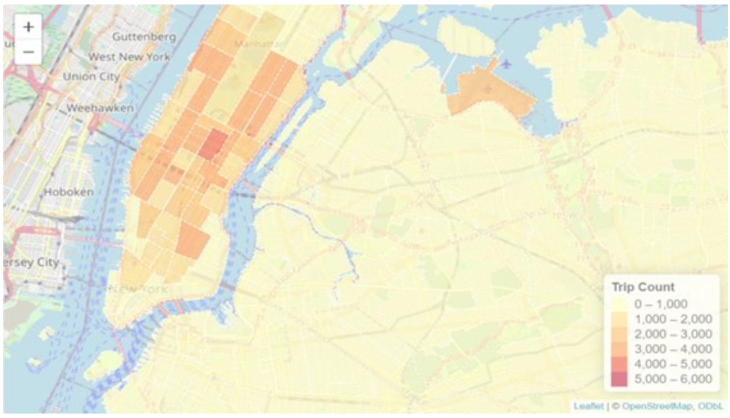

Figure 1. Taxi Service Distribution and Demand Hot spots

Specifically, the number of taxi pickups and drop-offs significantly increases in financial districts (such as Wall Street) and tourist areas (such as Central Park), indicating a higher reliance on

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transportation services in these areas. The high demand for transportation in these regions affects not only vehicle speeds but also the overall traffic flow and air quality of the city.

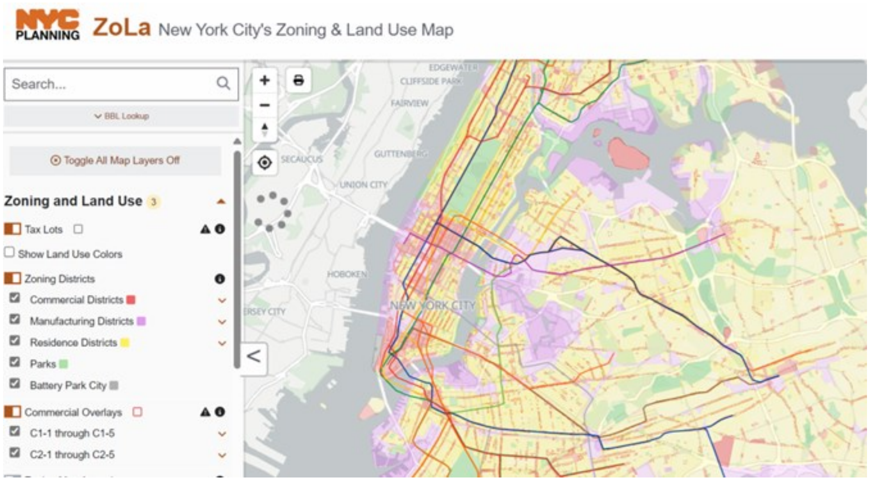

Figure 2. New York City's Zoning and Land Use Map from ZoLa | NYC's Zoning & Land Use Map.

When relating to the land use of New York City, commercial districts are almost the same areas with the highest demand for taxi operation. The data shows that commercial areas have highest population, leading to the result with greatest need for taxis as a way for transportation.

3.2. Overlap Between Air Pollution Hotspots and Taxi Operations

Combining the analysis of air pollution data, the results show that areas with the most frequent taxi operations are often also the areas with higher levels of air pollution.[6] The study reveals that, in particular, the concentrations of PM2.5 and NOx (nitrogen oxides) show a significant upward trend in areas with dense taxi operations.

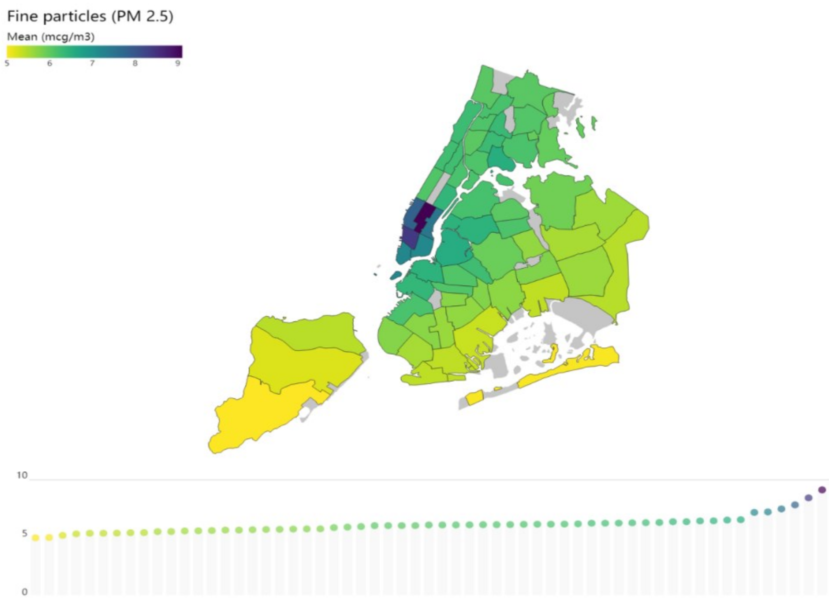

Figure 3. Distribution of air pollution(PM2.5)

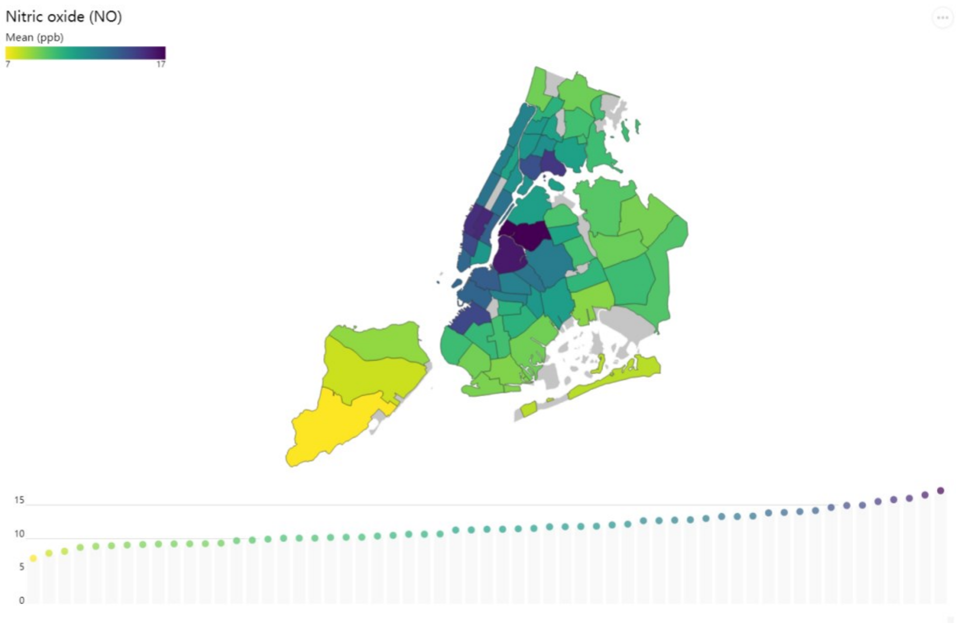

Figure 4. Distribution of air pollution(NO)

The areas concentrated with taxi services, such as Downtown and Midtown Manhattan, are not only transportation hubs but also the core areas of commercial activities. Due to the large number of vehicles gathering, the air pollution levels in these areas are significantly higher than in other regions. In these areas, the concentration of PM2.5 often exceeds health standards, and the high concentration of NOx further indicates the significant negative impact of vehicle emissions on local air quality. In addition, traffic congestion also increase the extent of air pollution.[7]

Moreover, through the spatial overlap analysis of air pollution hotspots and taxi operation data, it can be seen that these areas are often also densely populated, further increasing the threat to public health. The overlap between taxi operations and air pollution highlights the environmental challenges in urban transportation planning, calling for more policy interventions to mitigate the impact of traffic emissions on the environment.

4. Conclusion

This study utilizes Geographic Information Systems (GIS), big data, and spatiotemporal analysis models to reveal the spatial relationship between taxi service distribution and air pollution in New York City. The findings highlight that taxi operations significantly contribute to air pollution, particularly in high-demand areas such as business districts and transportation hubs. By analyzing taxi demand patterns and land use types, the study proposes a series of strategies to optimize taxi scheduling and distribution with the goal of reducing air pollution and enhancing service efficiency.

The significance of these findings lies in the data-driven decision support they provide to urban planners, transportation managers, and environmental regulators. The study offers insights that can help design more effective taxi scheduling strategies and implement air pollution control measures. By leveraging predictive models and understanding land-use patterns, it is possible to better allocate taxi resources, balance supply and demand, and mitigate the environmental impacts of transportation systems.

Moreover, while the study is focused on New York City, the methods and insights derived from the research can be applied to other major cities facing similar transportation and environmental challenges. [8]These findings contribute to sustainable urban transportation management, providing valuable lessons that can be adapted to different urban contexts to promote cleaner and more efficient transportation systems globally.

Here are some potential methods might be helpful to reduce the impact of taxi routes on air pollution.

Optimizing Dispatch and Route Planning. Using big data and real-time traffic information can significantly optimize taxi dispatch and route planning. By avoiding congested areas and high-pollution zones, taxis can reduce idle time and unnecessary driving, thus lowering emissions. Dynamic routing systems, which adjust based on current demand and traffic conditions, can also minimize empty rides and ensure more efficient taxi operations in urban environments.

Promoting the Use of New Energy Vehicles. Encouraging the adoption of electric taxis is a key strategy for reducing air pollution.[9] More taxi stations of electric taxis should be considered by government. In addition, places which have high demand for taxis should also be equipped with more taxi stations.[10] Governments can encourage taxi companies to transition to electric vehicles through subsidies or tax benefits. Additionally, expanding the charging infrastructure in key areas such as taxi stands, transportation hubs, and popular pickup locations can make electric taxis a more viable and convenient option for drivers, further reducing emissions.

Policy Interventions and Restrictions. Implementing area restrictions and congestion charges can discourage the use of high-emission taxis in pollution-prone areas. By allowing only electric or low-emission vehicles in city centers or during peak pollution times, these policies can directly reduce air pollution. Congestion charges and emission taxes can also motivate taxi drivers to adopt cleaner practices, such as avoiding unnecessary trips or switching to greener vehicles.

Shared Mobility Platforms and Ride-Sharing Services. Promoting ride-sharing services through platforms can reduce the total number of taxi trips and emissions by matching multiple passengers traveling along similar routes. More efficient passenger matching algorithms can increase vehicle occupancy, reduce total driving distance, and minimize the number of empty taxis on the road, making taxi services more sustainable and environmentally friendly.

Intelligent Traffic Management. Optimizing traffic signal timings in high-traffic areas can reduce idling and improve the flow of traffic, thus decreasing taxi emissions. Additionally, integrating vehicle-to-infrastructure (V2I) technology enables taxis to communicate with traffic management systems, allowing dynamic adjustments to routes based on real-time traffic data, reducing congestion and improving efficiency.

Demand Forecasting and Supply-Demand Matching. Using historical data to predict demand hotspots allows taxis to be pre-positioned in areas with higher expected passenger volumes, reducing empty rides and maximizing efficiency. Some theoretical model was developed to deal with taxi operation and scheduling for automated vehicle fleets. [11]Dynamic adjustments to taxi distribution can ensure that supply meets demand without over-saturating certain areas, thus avoiding unnecessary driving and pollution.

Improving Driving Behavior. Training taxi drivers in eco-friendly driving techniques, such as avoiding rapid acceleration and hard braking, can help reduce fuel consumption and emissions. Installing driver behavior monitoring systems in taxis provides real-time feedback, encouraging smoother driving habits that are both energy-efficient and environmentally friendly.

Promoting Non-Motorized Transport. Supporting non-motorized transport options, such as shared bikes and pedestrian-friendly areas, in high-pollution zones can reduce short taxi trips, leading to lower emissions. Additionally, promoting the use of public transportation by improving connectivity between taxis and transit hubs can reduce reliance on taxis, contributing to a more sustainable urban transportation ecosystem.

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