UDC 656.1
DOI https://doi.org/10.52171/herald.312

Temporal and Spatial Analysis of Surface Transport Density in an Urban Environment (Case Study of Binagadi District, Baku City)

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Abstract

The article examines urban transport in the capital of Azerbaijan, Baku, focusing on the impact of traffic congestion on travel efficiency, particularly in the Binagadi district. Traffic congestion patterns are analyzed with emphasis on the main streets experiencing the greatest delays during peak hours. The study is based on a dataset that records congestion by district, street, and time intervals, enabling a relative analysis of traffic distribution. The methodology includes determining the percentage of busy streets, comparing morning and evening peak periods, and identifying the most problematic areas. The article proposes the application of simulation-based approaches to optimize urban traffic and reduce congestion. As a result, the findings provide a foundation for developing and testing effective traffic management strategies using future simulation models in the Unity environment.

Keywords: Traffic congestion, urban mobility, peak hours, Baku, transport modeling

Submitted *24 October 2025*
Accepted *8 September 2026*
Published *25 September 2026*

For citation:
A.J. Hasanov
[Temporal and Spatial Analysis of Surface Transport Density in an Urban Environment (Case Study of Binagadi District, Baku City)]
Herald of the Azerbaijan Engineering Academy, 2026, vol. 18 (3), pp. 78-84
ISSN (p): 2076-0515, ISSN (e): 2789-8245
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Şəhər mühitində yerüstü nəqliyyat sıxlığının zaman və məkan analizi (Bakı şəhəri, Binəqədi rayon nümunəsində)

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Xülasə

Məqalədə Azərbaycanın paytaxtı Bakıda, xüsusilə Binəqədi rayonu üzrə şəhər nəqliyyatında pik saatlarda yaranan sıxlığın zaman və məkan üzrə analizi tədqiq olunub. Tədqiqatda əsas diqqət ən çox gecikmə müşahidə olunan küçələrə yönəldilərək, yol hərəkəti tıxaclarının formalaşma modelləri araşdırılıb. Bu məqsədlə rayon, küçə və saat qurşağı üzrə tıxacları əks etdirən məlumat bazası əsasında nisbi təhlil aparılıb. Metodologiya çərçivəsində işlək küçələrin faiz göstəriciləri müəyyən edilmiş, səhər və axşam pik saatları müqayisə olunmuş və problemli sahələr identifikasiya edilib. Məqalədə şəhər nəqliyyatının optimallaşdırılması və tıxacların azaldılması istiqamətində gələcək simulyasiya yanaşmalarının tətbiqi təklif irəli sürülüb. Nəticədə əldə olunan göstəricilər əsasında şəhərdə yol hərəkəti tıxaclarının azaldılmasına yönəlmiş effektiv strategiyaların hazırlanması və onların Unity mühitində simulyasiya modelləri vasitəsilə sınaqdan keçirilməsi üçün əsas formalaşdırılıb.

Açar sözlər: tıxac, şəhər mobilliyi, pik saatlar, Bakı, nəqliyyat modelləşdirməsi

Анализ временной и пространственной плотности наземного транспорта в городской среде (на примере Бинагадинского района города Баку)

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Аннотация

В статье исследовано влияние транспортной загруженности на эффективность передвижения в столице Азербайджана – Баку, с акцентом на Бинагадинский район. Рассмотрены модели транспортных заторов, особенно в часы пик, с выделением основных улиц, на которых наблюдаются наибольшие задержки. Анализ выполнен на основе базы данных, фиксирующей заторы по районам, улицам и временным интервалам, что позволило провести относительное исследование распределения транспортной плотности. В рамках методологии определена доля загруженных улиц, проведено сравнение утренних и вечерних часов пик, а также выявлены наиболее проблемные участки. В статье предложен подход к использованию симуляционных моделей для оптимизации городского транспорта и снижения уровня заторов. В результате полученные данные могут служить основой для разработки и тестирования эффективных стратегий управления транспортными потоками с использованием моделей симуляции в среде Unity.

Ключевые слова: транспортные заторы, городская мобильность, часы пик, Баку, транспортное моделирование.

Introduction

Traffic congestion has become a daily reality in nearly every major city in the world, and Baku is no exception. As the capital's population and private vehicle fleet grows, the city's highway and street network face increased demand. This increase, particularly during rush hour, leads to long queues, commuting delays, and reduced reliability. Beyond personal inconveniences, traffic congestion also has far-reaching socioeconomic and environmental consequences, including reduced productivity, increased fuel consumption, and deteriorating air quality [1].

One of the key characteristics of traffic congestion in the capital is its spatial and temporal variability. While traffic congestion in the central district's peaks during the morning/evening rush hours, surrounding areas are relatively less affected. Traffic flow is predominantly directed toward the city center in the morning, while it reverses in the evening; weekday and weekend congestion, as well as school and work schedules in the spring and fall, reinforce these dynamics. Weather conditions (rain, wind), random events (accidents, breakdowns), and planned work (road repairs) all exacerbate daily variation.

The structural causes of traffic congestion are diverse: rapid increases in private vehicle use, centralized land use (concentration of businesses and services in the city center), inadequate parking management, limited capacity at critical points (intersections, junctions), inability to coordinate signaling plans with peak demand, and conflicts between pedestrians, public transportation (especially buses), and road space [2]. These factors, combined, lead to both reduced speeds and increased delays during rush hour.

In recent years, the emergence of Big Data technologies has created new opportunities for the analysis and management of complex urban traffic systems. Big Data analytics enables data-driven decision-making in transportation planning by combining large datasets from sensors, GPS systems, mobile devices, and IoT-based monitoring tools [3].

To visualize and test these data-driven insights, Unity programming provides a powerful simulation environment that allows researchers to create interactive digital twins of urban areas. By combining Big Data analytics with Unity's real-time visualization and physics-based modeling capabilities, it is possible to simulate different traffic scenarios, evaluate the effectiveness of intervention strategies, and predict the impact of future urban development.

Purpose of the work

The main goal of this article is to analyze the spatial and temporal distribution of traffic jams across Binagadi district, to analyze which streets are most congested during rush hours. The study attempts to determine whether the morning (AM) or evening (PM) peak hours bring greater pressure on the road network and focus attention on the most critical roads that consistently cause delays. The problem discussed in this article stems from the persistent imbalance between the city's rapid growth in use of the private car and the limited capacity of the city's road infrastructure.

The study also aims to explore how Unity-based simulation modeling can be combined to better understand traffic congestion behavior and visualize traffic patterns in real time. By integrating real-world traffic data into a digital simulation environment, this approach aims to support more accurate and data-driven decision-making for future urban mobility planning in Baku.

Problem statement

From a policy view, traffic jam is not only travel time load also it has real economic, environmental, and social costs. Longer and

less predictable travel reduce productivity and logistics safety, stop-and-go conditions increase fuel consumption and emissions, additionaly increased noise and air pollution negatively impacts public health. More importantly the load is unequel across time and space: a small group of corridors can account for a disproportionate share of the delay across the region and can vary significantly between morning and evening due to peak hours, directional commuting patterns, and local land-use mixes. These features make a corridor-level, time-dependent analysis both necessary and feasible.

Research methods

This study will focus on analys the level of traffic congestion in the Binagadi district of Baku. This districts weas selected primarily because they hold strategic importance in transportation network. Binagadi district have major highways and main roads that serve as key corridors for daily commuting, freight transport, and inter-district connectivity.

Moreover, this district are frequently specify in public reports and the media as areas where heavy traffic jams regularly occurs, making them suitable examples for our study.

A preliminary study was started with using Google Maps traffic data to capture traffic flow dynamics for the Binagadi. Google Maps platform allow us to collect real-time and historical data on traffic density. This step let us to systematically track the streets and intersections most affected by traffic congestion. Special attention was paid to observing traffic variations at different time intervals all through the day.

This research show the level of congestion, delays on congested areas and based on this data, the variation in motor vehicle speeds and delays during normal and rusk hours for the Binagadi and Sabunchu districts step by step. As a result, we aim to highlight not only where congestion occurs, but also how it grows temporally and spatially across districts, making this study a cornerstone for understanding urban mobility problems in Capital city. Our research has shown that especially in Binagadi district, traffic jams are observed during peak hours on Sumgayit Highway, “Baksol” road (M.A. Rasulzade settlement) and Binagadi Highway. The areas where traffic jams are observed are shown in the figure below (Figure).

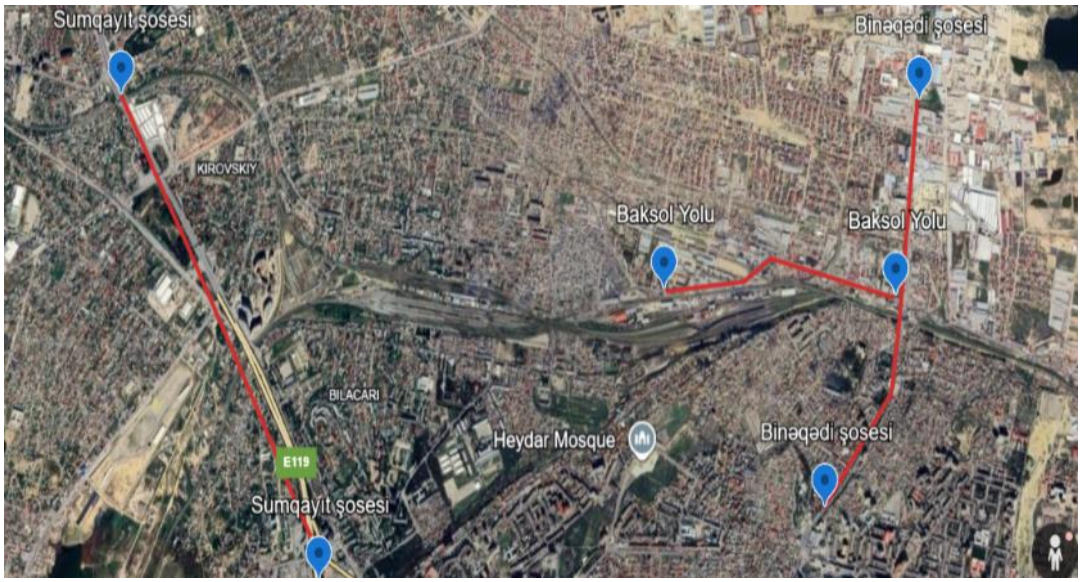

Figure – Traffic jams in Binagadi district

As seen in the image above, streets experiencing traffic congestion are marked with red lines. The primary reason for the congestion in these dotted corridors is that they serve the major highways serving the settlements of Khirdalan, Mehdiabad, and Fatmayi. These areas provide significant traffic flow to the Binagadi district, making these routes critical transportation routes. However, the structural limitations of the roads, their narrow widths, insufficient highway capacity, and the lack of alternative connections contribute to the impact of traffic congestion. In many scenarios, average speeds drop well below normal operating levels during periods of traffic congestion, causing delays and increased fuel consumption. This problem not only disrupts daily transportation but also contributes to broader economic and environmental costs for the region.

Data needed to calculate average traffic speeds during rush hour on these streets were obtained from maps and traffic information sources. According to these data, the approximate length of traffic congestion on Baksol Road is approximately 2 km, on Sumgayit Highway it reaches 3.9 km, and on Binagadi Highway it reaches approximately 2.6 km. These measurements form the basis for estimating traffic speeds and delays during rush hour.

We use the following equation (1) to calculate the delay during rush hour. In the formula, ΔT is the delay T_{peak} is the peak time, and T_{off} is the off peak time.

$$\Delta T = T_{peak} - T_{off} \quad (1)$$

Based on travel time estimates, the 2 km part of Baksol Road increases from 8 minutes during off-peak hours to 18 minutes during peak hours, representing a delay of 10 minutes. On the Binagadi highway, the 2.6 km section increases from 14 minutes to 30 minutes, representing a delay of up to 16 minutes. On the Sumgayit highway, the 3.9 km section increases from 12 minutes to 30 minutes, representing a delay of 18 minutes.

Based on the information we have obtained. For the article, it is possible to calculate the average Speed for peak hour (km/h) (2) and peak off hour (km/h) (3), how much the speed decreases during traffic jams (4), and the Travel Time Index (TTI) (5). The following formulas were used to perform these calculations [4]. In equation (2), V represents average speed km/h, distance in km, and T represents travel time in minutes.

$$V_{off} = \frac{D \times 60}{T_{off}} \quad (2)$$

$$V_{peak} = \frac{D \times 60}{T_{peak}} \quad (3)$$

$$\%drop = \frac{V_{off} - V_{peak}}{V\ off} \times 100\% \quad (4)$$

and

$$TTI = \frac{T_{peak}}{T_{off}} \quad (5)$$

Discussion of the results

These calculations are crucial for relieving future traffic congestion because they transform raw observations into comparative, corridor-level evidence of travel time performance across different routes and peak hours. We place each corridor on the same metric scale, which allows for similar comparisons between AM and PM peaks and between streets of different lengths and traffic roles. This standardization supports direct prioritization, guides operations, and informs design.

Methodologically, to ensure repeatability and fair comparison, metrics are calculated across fixed origin-destination segments within consecutive AM/PM windows. While individual values may vary from day to day due

to events or weather conditions, the set of indicators is sufficient to detect persistent hotspots and directional patterns. The table below provides the corridor-level results used in our analysis. (Table).

Table – Summary of the travel time metrics in Binagadi district

Highway	**D (km)**	T_{off} **(min)**	T_{peak} **(min)**	ΔT	V_{off} **(km/h)**	V_{peak} **(km/h)**	**%drop**	**Travel Time Index**
Baksol	2.0	8	18	10	15	6.67	55.6%	2.25
Binagadi Highway	2.6	14	30	16	11.14	5.20	53.3%	2.14
Sumgayit Highway	3.9	12	30	18	19.50	7.80	60%	2.50

A comparison of AM and PM windows shows that the impact of peak hours can be asymmetric in terms of space and direction: morning flows tend to increase congestion mainly towards the center, while evening flows tend to increase congestion in the opposite direction. This behavior is related to land-use (schools, offices, commercial areas) and the capacity of the nodes; therefore, corridor-specific design of operational measures is important.

TTI (Travel Time Index) of 1.0 indicates no congestion, ~1.2 indicates light congestion, and >1.5 indicates heavy congestion [5]. As can be seen from the results above, the TTI index is quite high on the three major highways in the Binagadi area. Overall, these results indicate that higher ΔT and TTI values reduce reliability for buses and transit and provide insights into scheduling buffers, fleet sizes, and forward planning. These results can be recalculated after the measures are implemented, allowing for before/after evaluation and transparent performance tracking.

These results clearly reveal the spatial and temporal concentration of peak hour traffic in Binagadi and indicate the need for targeted interventions in priority corridors.

Conclusions

This study provides a simple and reproducible framework for measuring congestion at the corridor level and time zone (AM/PM) in Binagadi. Raw observations were translated into metrics such as delay, average speed, speed reduction, and Travel Time Index, which allow for fair comparisons between routes. Significant causes of delays are concentrated at a few bottlenecks and short intersections, suggesting that not only high demand but also geometry, signal management, and off-road (parking/loading) friction play a role.

From a practical perspective, the metrics we developed provide a concrete basis for prioritization: which junctions and corridors provide the most short-term operational improvements; and which sections require medium-term design updates.

The O-D (Origin–Destination) measurement calculation of our research will help to study traffic jams not only for Binagadi but also for other districts of Baku in the future. In addition, this information will help to prepare a database of software programs used to minimize traffic jams in the future. In particular, this research is one of the first steps

in our topic of reducing traffic jams and developing appropriate algorithms with the Unity engine that we are currently working on.

Although methodological limitations exist, the framework can be replicated and expanded. If necessary, simulated scenarios and visual representation in Unity can enhance stakeholder engagement and accelerate decision-making.

Overall, the presented framework provides a transparent picture of where and to what extent congestion occurs during peak hours in Binagadi and creates a solid foundation for moving from measurement to management.

Conflict of Interest

The author declares there is no conflict of interest related to the publication of this article.

REFERENCES

1. https://www.eea.europa.eu/en/analysis/publications/sustainability-of-europes-mobility-systems/air-pollution?utm_source
2. **Rasulov G., Burjaliyeva S.** Bakı şəhərində yolların tıxac problemi və monorels nəqliyyat vasitəsinin təklifi, International Scientific and Practical Conference Azerbaijan in the International Transport System, Azerbaijan, Baku, 2024, s.241-242.
3. **Abbasova, P.** Big Data Analysys in Cyber Physical Systems. Herald of the Azerbaijan Engineering Academy, 16(3), 81–86. https://doi.org/10.52171/2076-0515_2024_16_03_81_86
4. U.S. Department of Transformation, Federal highway Administration, The Urban Congestion Report (UCR): Documentation and Definitions, Webinar materials, 2015
5. https://transportation.ky.gov/Congestion-Toolbox/Pages/Congestion-Measures.aspx?utm_source