SPATIO-TEMPORAL ANALYSIS OF TRAFFIC CONGESTION IN ULAANBAATAR CITY TO ADDRESS URBAN MOBILITY CHALLENGES

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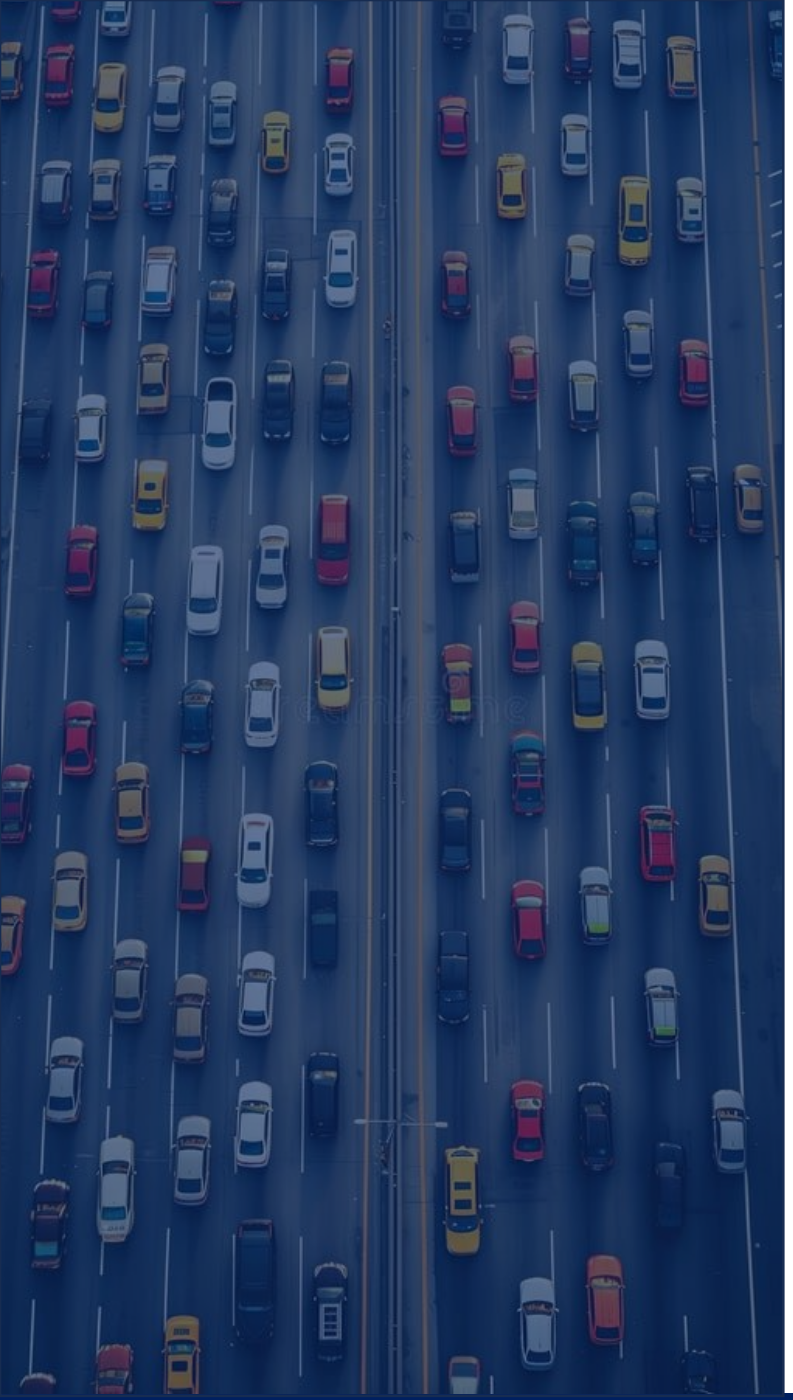


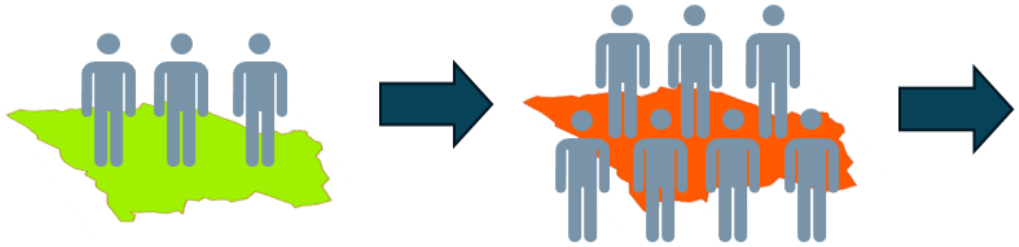
CONTENTS

Urban growth & Mobility challenges

Total territory: Less than 1%
Total population: More than 50%

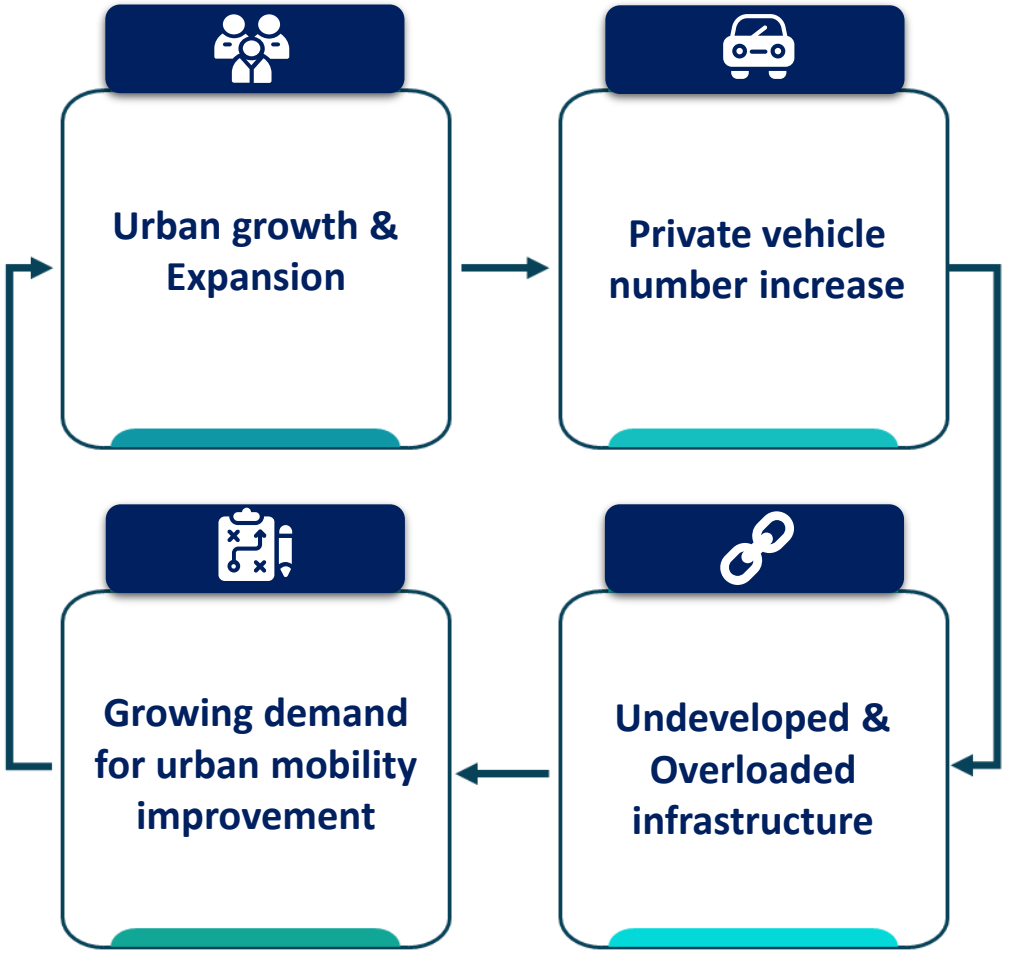
Initial plan (1950):
0.6 million people[1]

Current population (2024):
1.7 million people[2]



As of 2020, the area of suitable settlement zones had expanded by **16.4%** and it's continuing [3]

Current situation & Interconnected factors



Sources: *[1] Myagmartseren. P, Myagmarjav. I, Enkhtuya. N, Byambakhuu. G, Bazarkhand. T (2020)*
[2] Statistics from the National Statistical Office on the resident population of Mongolia (2023-2024)
[3] Batsuuri, B., Fürst, C., & Myagmarsuren, B. (2020).

Key issues in Urban mobility

1

Intense traffic congestion

Residents spend about **2.5 hours** in traffic daily, with peak-hour speeds dropping to just **8.9 km/h** [4]

2

Limited public transit coverage

Over **60%** of Ulaanbaatar's population relies on public transport, only about **2%** of vehicles are public buses [5]

3

Low infrastructure quality

Ulaanbaatar's population grew by **26%** in the last decade, but road infrastructure expanded by only **19%** [6]

4

Environmental concerns

Traffic contributes **29%** of Ulaanbaatar's air pollution, with vehicle emissions alone accounting for **16.1%**, especially during winter [7]

Sources: *[4] Batbayar, G., Baasanjav, D., & Tserendorj, G. (2021). Public transportation inefficiencies and congestion in Ulaanbaatar: A policy review. Mongolian Journal of Transportation, 14(2), 67–78.*
[5] Enkhbold, B., & Myagmarjav, O. (2023). Urban mobility and traffic congestion in Ulaanbaatar: Challenges and policy responses. Journal of Mongolian Urban Studies, 5(2), 45–59.
[6] Ganbaatar, U. (2020). Traffic congestion in Ulaanbaatar: Trends and challenges. Mongolian Journal of Urban Studies, 9(1), 43–58.
[7] Soyol-Erdene, T. O., Ganbat, G., & Baldorj, B. (2021). Urban air quality studies in Mongolia: Pollution characteristics and future research needs. Aerosol and Air Quality Research, 21(12),

Research Gap

Spatio-Temporal analysis gap

Limited analysis of **where** and **when** traffic congestion occurs in Ulaanbaatar

Theoretical analysis gap

Unclear understanding of **how** urban factors influence traffic congestion

Modeling analysis gap

Absence of integrated and predictive modeling approaches.

Policy evidence gap

Unoptimized practical solutions for reducing traffic congestion

Outcome

Undermines the development of effective and sustainable traffic congestion solutions in Ulaanbaatar

Research Questions

What are the major traffic **congestion hotspots** in Ulaanbaatar, and how are they **spatially distributed**?

What urban mobility related **factors contribute** to the formation of these congestion hotspots?

When do traffic congestion **peak periods** occur in Ulaanbaatar, and what is their typical duration?

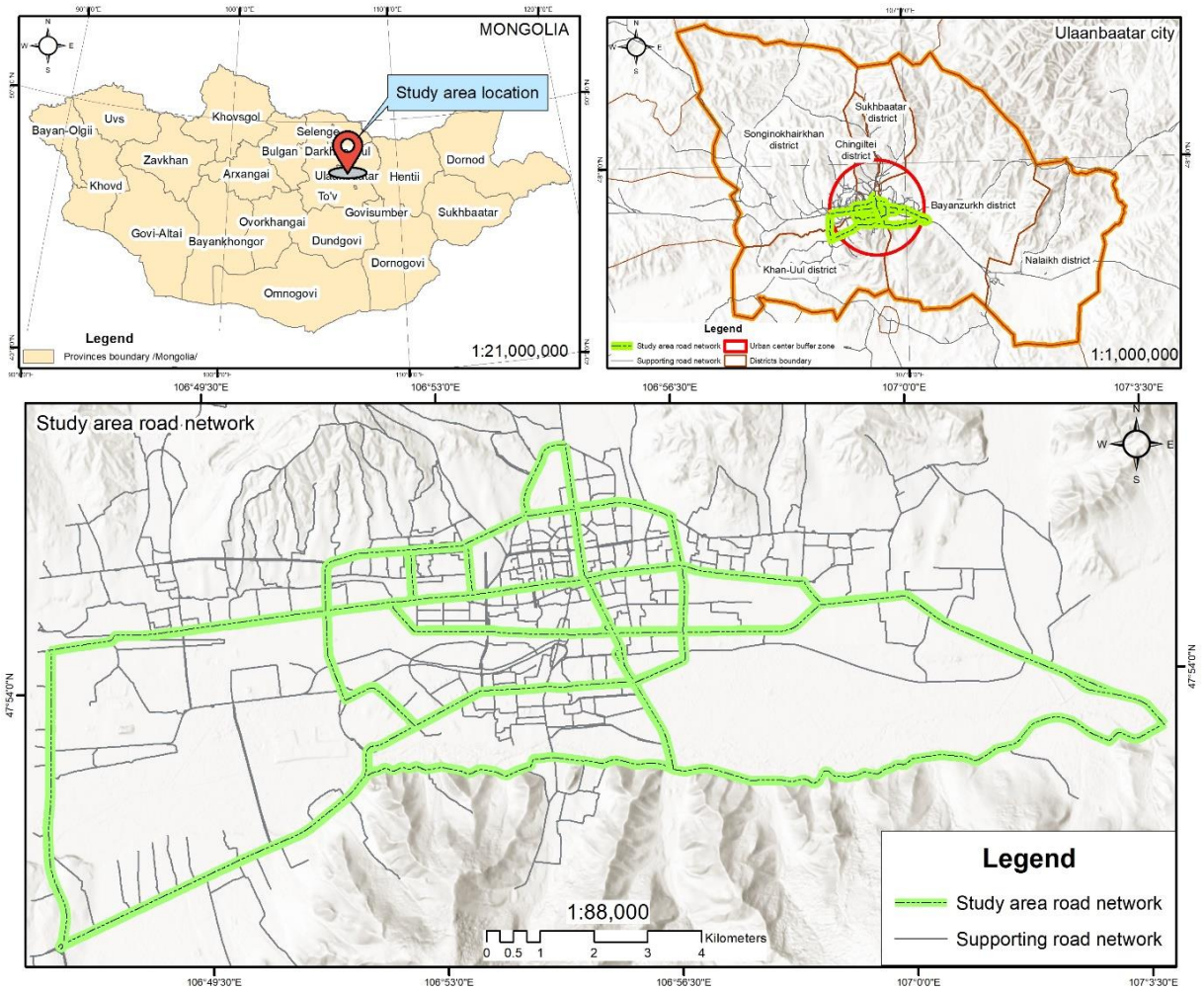
What strategies can be developed to **enhance** urban mobility **efficiency** and **reduce** traffic congestion?

Research Significance & Contributions

- Validates use of crowd-sourced traffic data
- Offers open GIS + OLS workflow for other cities
- Provides first segment-level urban form findings in Mongolia
- Adds Ulaanbaatar to global low-cost ITS research

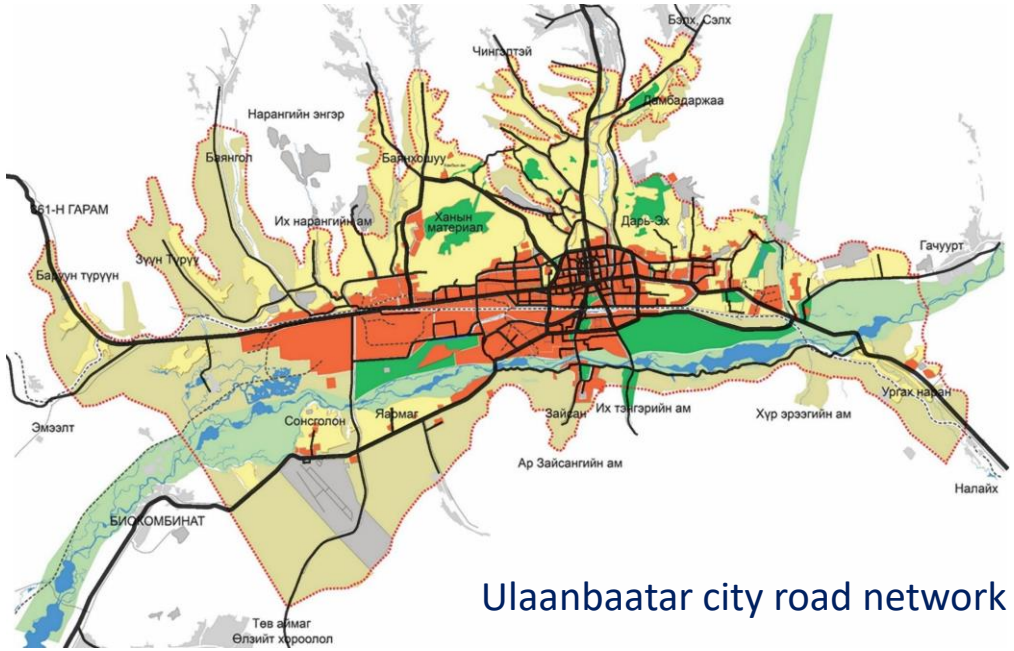
- Creates hotspot maps and daily congestion patterns
- Identifies high-priority corridors for interventions
- Sets baseline for future policy evaluations

Study area & Selected road network description



Research selected road network

The total length of Ulaanbaatar's road network is approximately **1200 km**, of which **70%** is located in built-up areas and **30%** in ger districts [8].



Ulaanbaatar city road network

In the research the central area's main road network has been selected. It covers approximately **170** km in total length.

Sources: *[8] Capital City Road Development Department, 2023*

Research methodological workflow

Data acquisition & Pre-processing

- Traffic congestion variables (independent variables)
  - Building density
  - City center proximity
  - Road network density
  - Land valuation zone
- Google Maps typical traffic layer (dependent variable)
  - 119 individual congestion pattern data → Geo-spatial data conversion (Geoprocessing)
- Land-use zone
- Intersection proximity
- Congestion pattern Geodatabase
- Data cleaning & Normalization

INPUT

Main data analysis/processing

- Temporal analysis of congestion
  - Hourly congestion pattern
  - Daily congestion pattern
  - Weekly congestion pattern
- Spatial analysis of congestion
  - Kernel density estimation (KDE)
  - Getis-Ord Gi*
- Correlation analysis between congestion variables
- Linear regression (OLS) analysis on congestion variables

PROCEDURE

Results & Recommendation

- Summary of key findings
- Discussion & Interpretation
- Policy implication recommendation

OUTPUT

Data collection and preparation

Google Maps Traffic layer data [9]

- Real-time data with historical traffic patterns to predict traffic conditions.
- Advanced machine learning models, including Graph Neural Networks
- Estimated travel times with over 97% accuracy.

→ Real Time Traffic Layer
→ Typical Traffic Layer

Study area Google Maps Traffic layers appearance

Google Maps Traffic layer vs General traffic data

STRENGTH

- High-resolution spatial data
- Comprehensive area coverage
- Easy visualization

WEAKNESS

- Not official traffic data
- Absence of quantitative traffic volume information

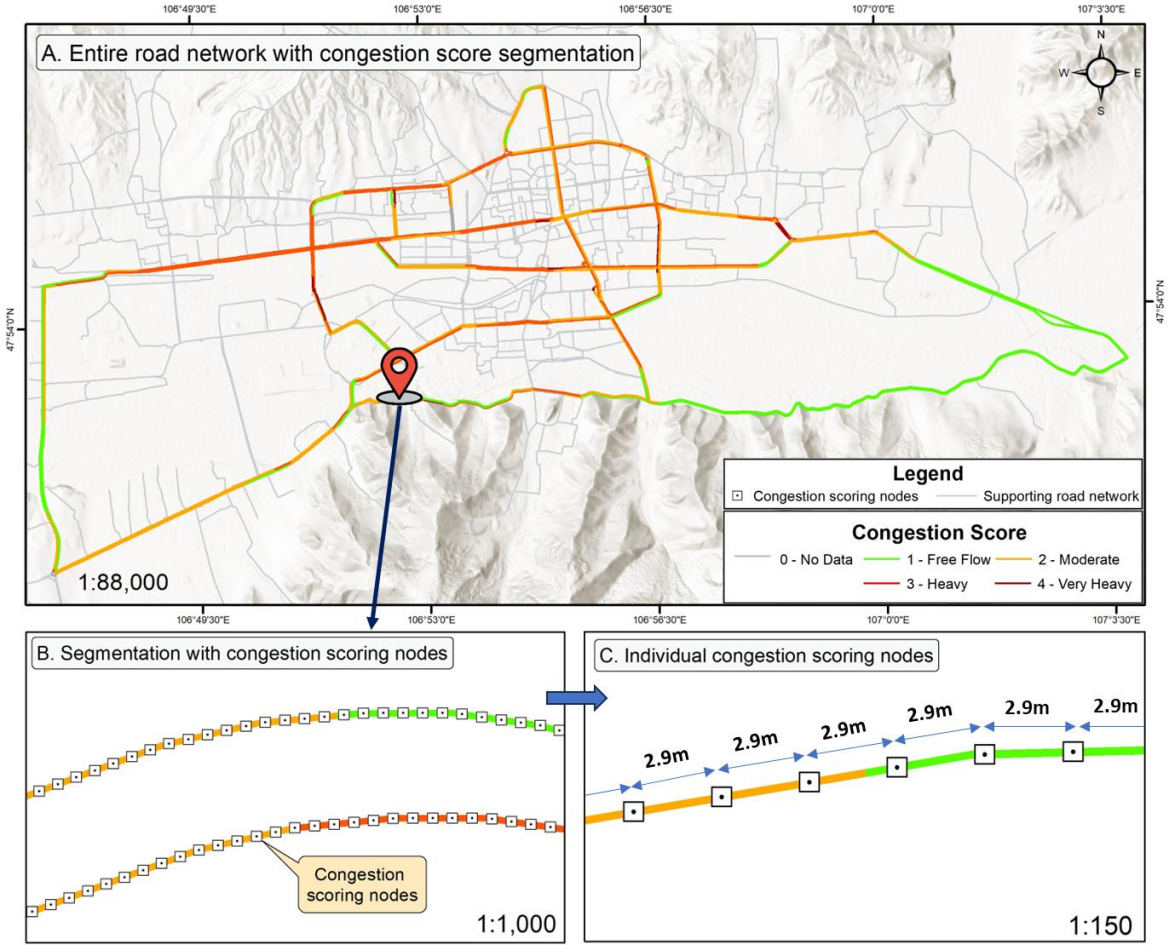
Google Maps traffic layer descriptions

Score	Description	Interpretation
1	Free-flowing traffic	Vehicles move without delay or slowdown.
2	Moderate traffic	Some slowdown is present, but still moves steadily.
3	Heavy traffic	Vehicles experience significant delays.
4	Severe congestion	Vehicles are moving very slowly or stopped.
N/A	Data not collected or unavailable	

Sources: *[9] Google Developers. (2024). Google Maps Platform documentation*

Traffic congestion pattern database process

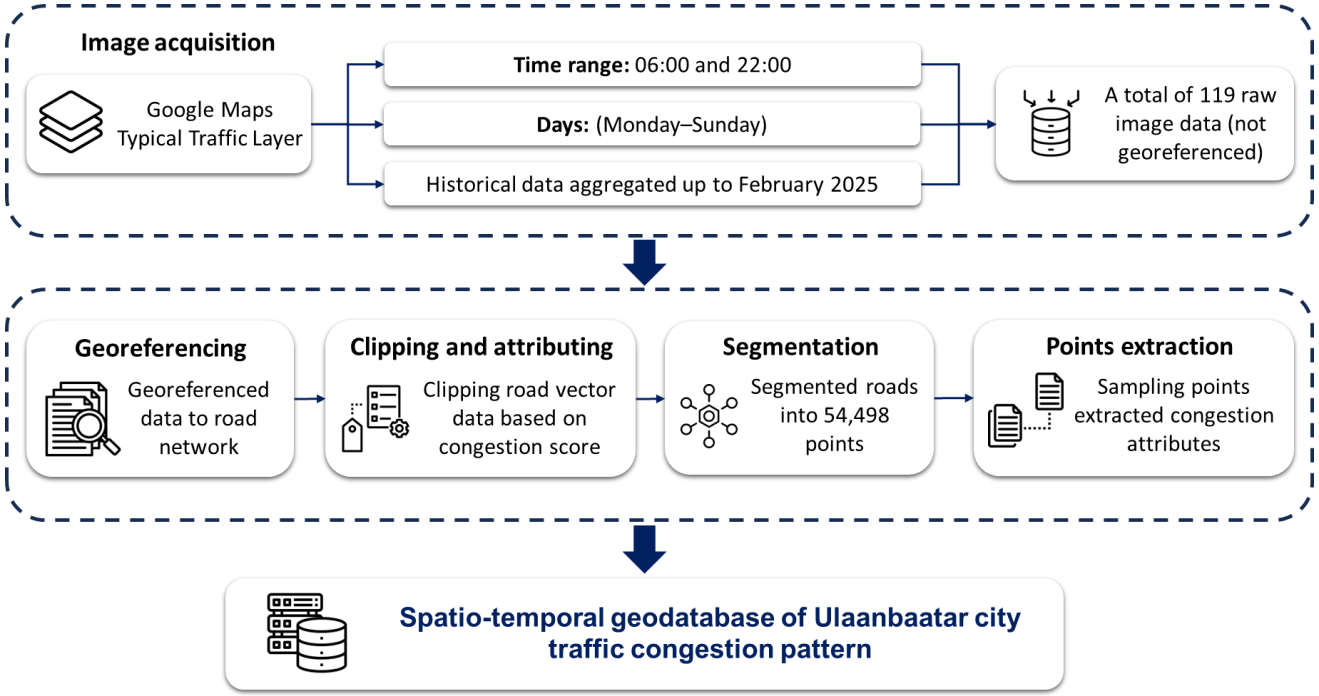
Segmented road network with assigned congestion scores



Time range and Road segmentation

Time range	- Data collected from 06:00 AM to 10:00 PM (one hour interval) - 7 days (Monday to Sunday) - Total individual hour data: 119 (17 hours × 7 days)
Road segmentation	- Main road network (170 km) = 54,498 individual segments - Each segment is approximately 2.9 meters long - Each segment assigned a unique ID

Traffic congestion Data pre-processing workflow diagram



Dependent & Independent Variables description table

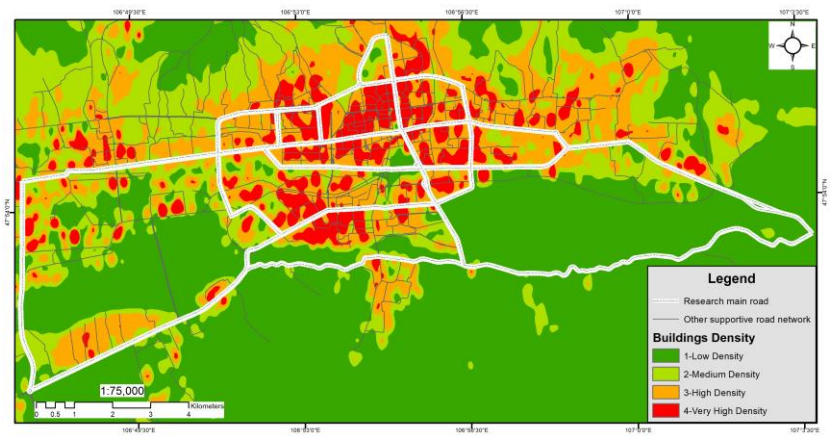
Variable name & Type	Description	Measurement type	Unit	Data source
Traffic Congestion Score /Dependent/	Traffic congestion per road segment and time slot	Ordinal (1–4)	Scale (1–4)	Google maps typical traffic Layer)
Land Use Zone /Independent/	Dominant land use around road segment	Categorical	Land-Use zoning type	General Agency for Urban Planning of Ulaanbaatar
Intersection Buffer Zone /Independent/	Whether segment lies within 150m of an intersection	Binary	Meters (radius = 150 m)	Calculated in GIS / spatial analysis/
Proximity to the City Center /Independent/	Proximity to the central area of the city	Continuous	Kilometers	Calculated in GIS / spatial analysis/
Building Density /Independent/	Intensity of buildings around the road segment	Continuous	Buildings/km²	Ulaanbaatar Land Management Information System / GIS
Road Network Density /Independent/	Total road length per unit area nearby	Continuous	km/km²	Capital City Road Development Department / GIS
Land Valuation Zone /Independent/	Land value classification per urban zoning	Ordinal (1–8)	Land valuation zoning number	Urban master plan

Variable Classification Framework (Scale-Based Overview)

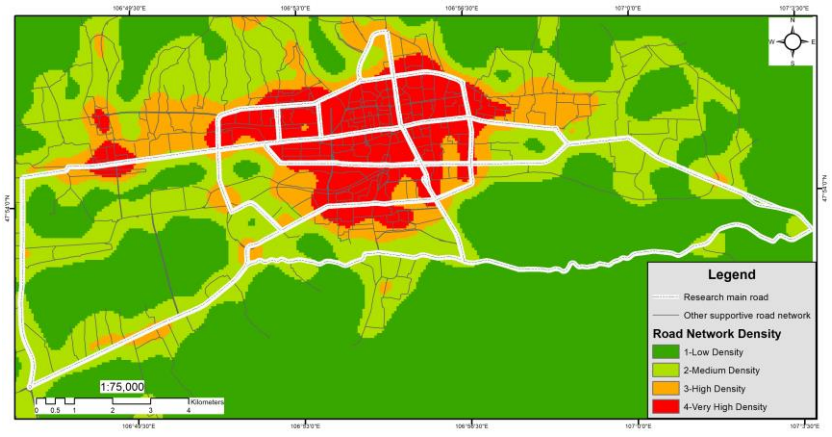
Variable	Scale 1	Scale 2	Scale 3	Scale 4
Congestion Score (Dep.)	1 = Free Flow	2 = Moderate	3 = Heavy	4 = Severe
Land Valuation Zone	1 = Low	2 = Medium	3 = High	4 = Very High
Building Density	1 = Sparse	2 = Moderate	3 = Dense	4 = Very Dense
Road Network Density	1 = Low	2 = Medium	3 = High	4 = Very High
Proximity to the city center	1 = Far	2 = Mid-distance	3 = Near	4 = Core Area

Mapping visualization of the independent variables

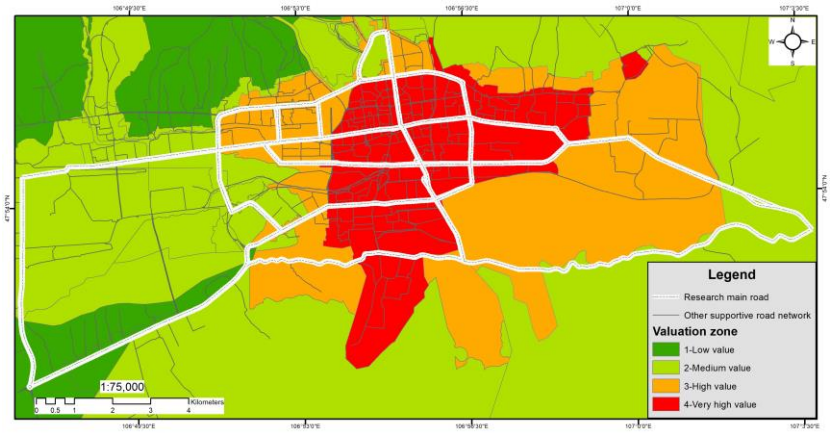
Building density



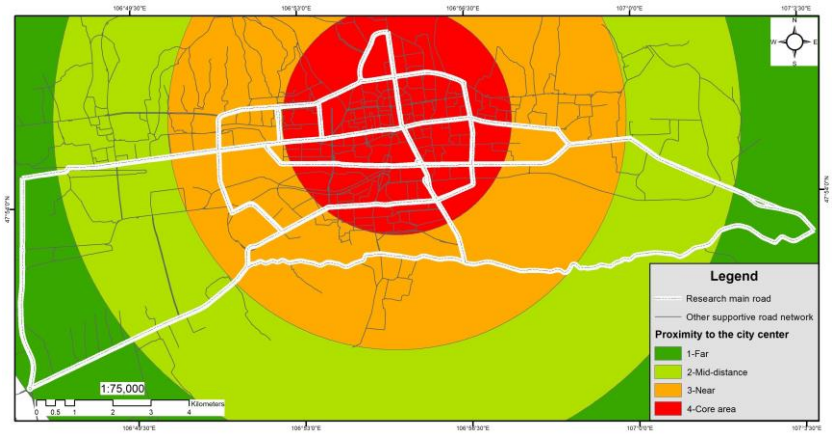
Road network density



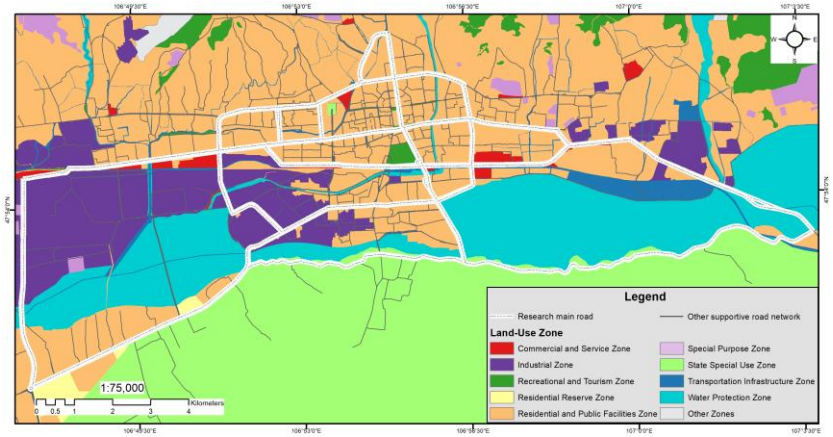
Land valuation zoning



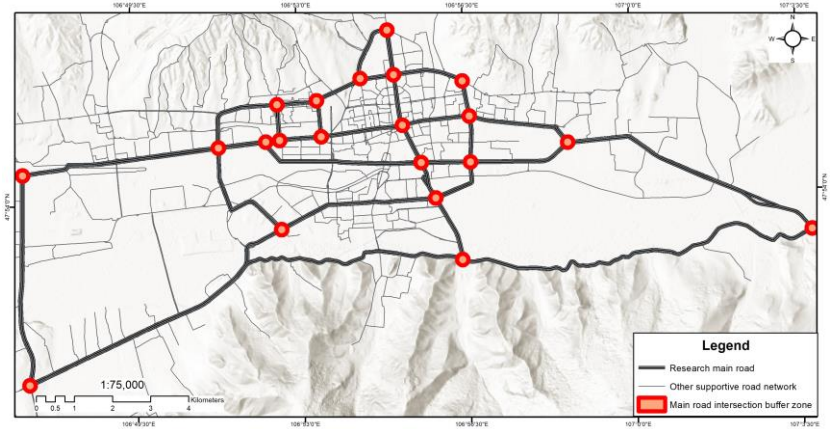
Proximity to the city center



Land use zoning



Intersection buffer zone

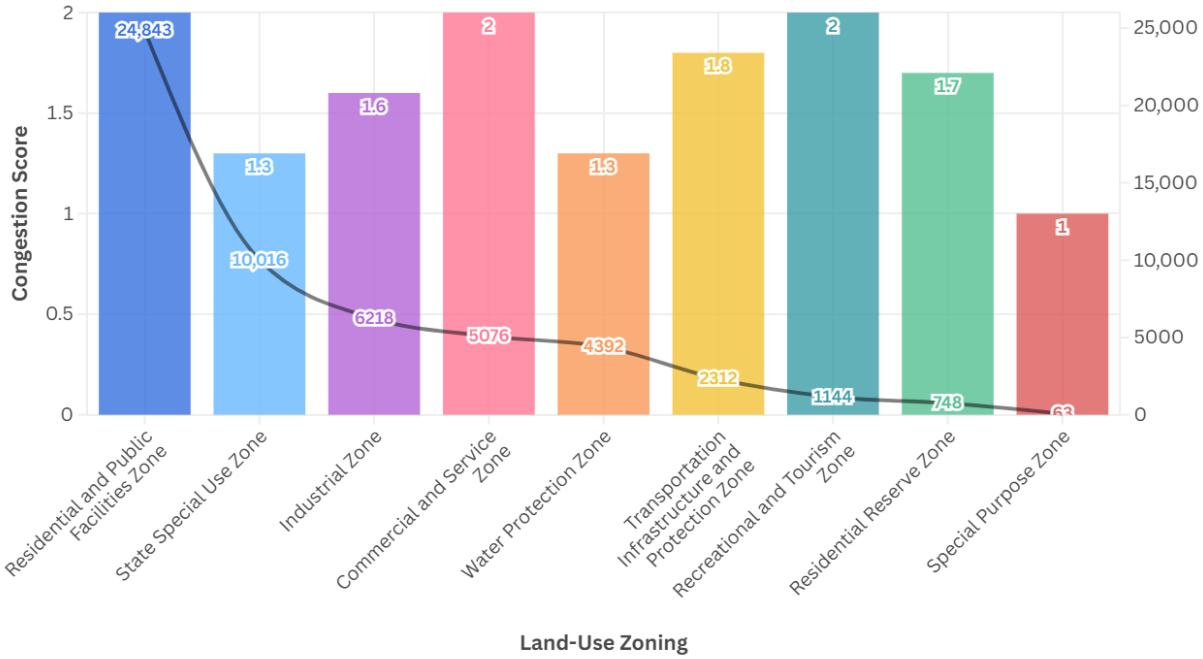


Traffic congestion patterns by land-use zones

Distribution of land-use zoning

Land Use Zoning	Percentage (%)	Segment Numbers	Average Congestion Score
Residential and Public Facilities Zone	45.30%	24,843	2.0
State Special Use Zone	18.30%	10,016	1.3
Industrial Zone	11.30%	6,218	1.6
Commercial and Service Zone	9.30%	5,076	2.0
Water Protection Zone	8.00%	4,392	1.3
Transportation Infrastructure and Protection Zone	4.20%	2,312	1.8
Recreational and Tourism Zone	2.10%	1,144	2.0
Residential Reserve Zone	1.40%	748	1.7
Special Purpose Zone	0.10%	63	1.0
Overall	**100%**	**54,812**	**1.8**

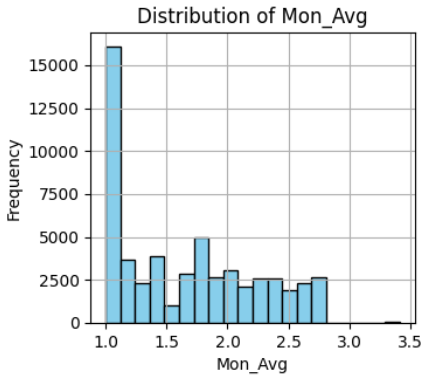
Land-use zoning distribution by segment count (%)

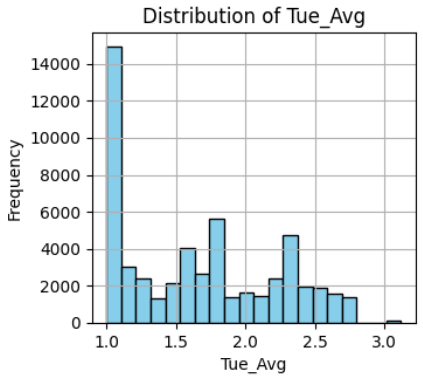


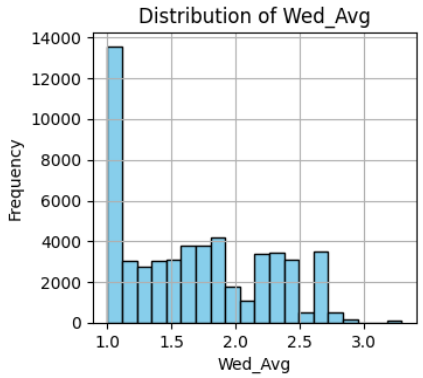
The most important focus zones:

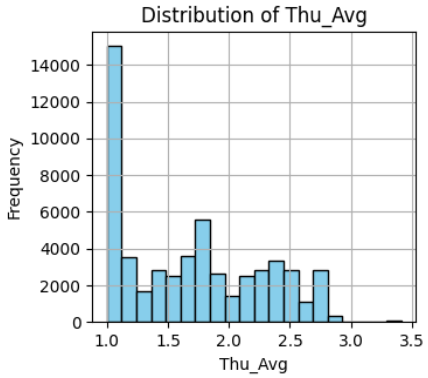
- Residential and Public Facilities zone
- Commercial and Service zone
- Recreational and Tourism zone

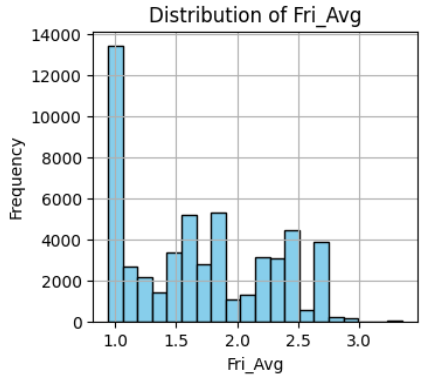
Weekly traffic congestion patterns

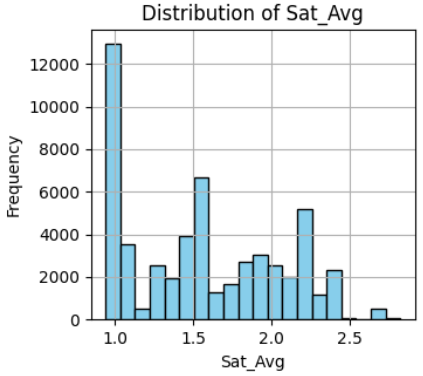


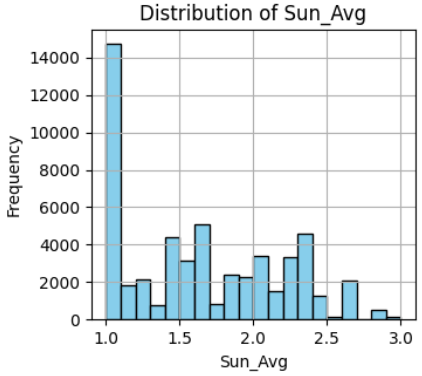




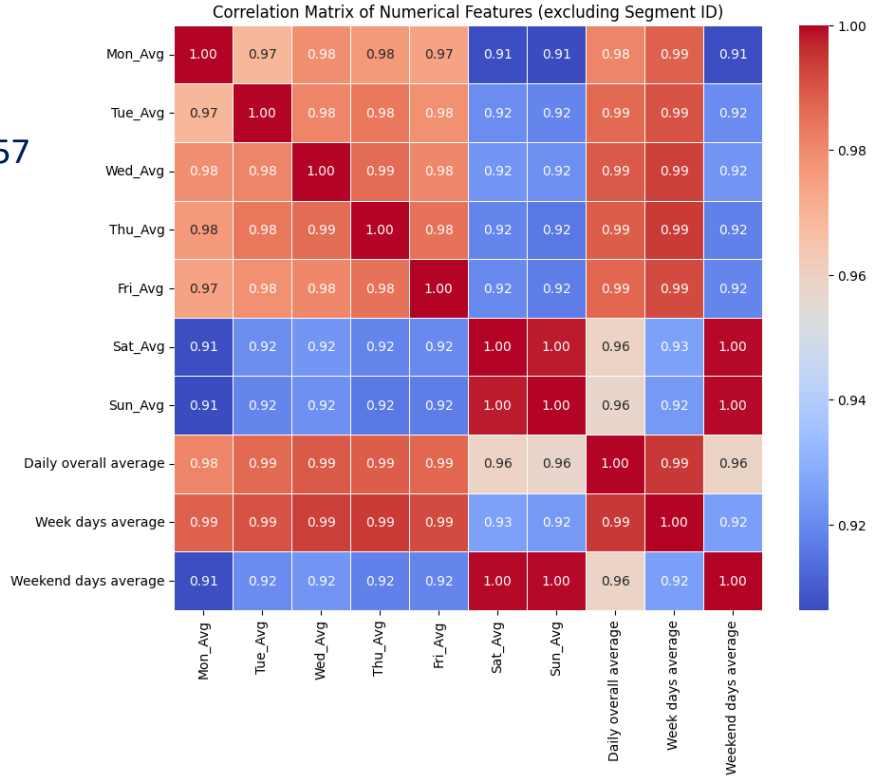


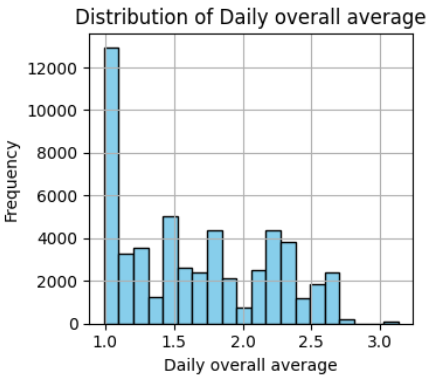


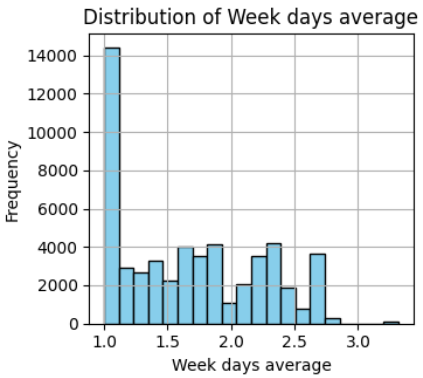


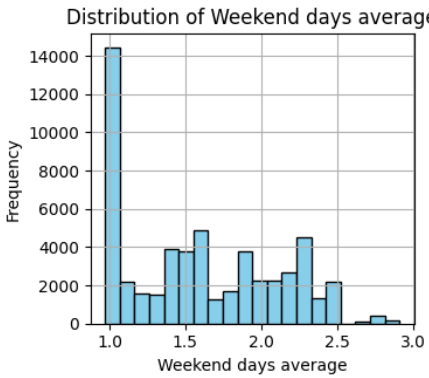


Highest Avg. Score: Friday 1.71
Lowest Avg. Score: Saturday 1.57
Weekday Avg. Score: 1.68
Weekend Avg. Score: 1.61
Overall Daily Avg. Score: 1.67



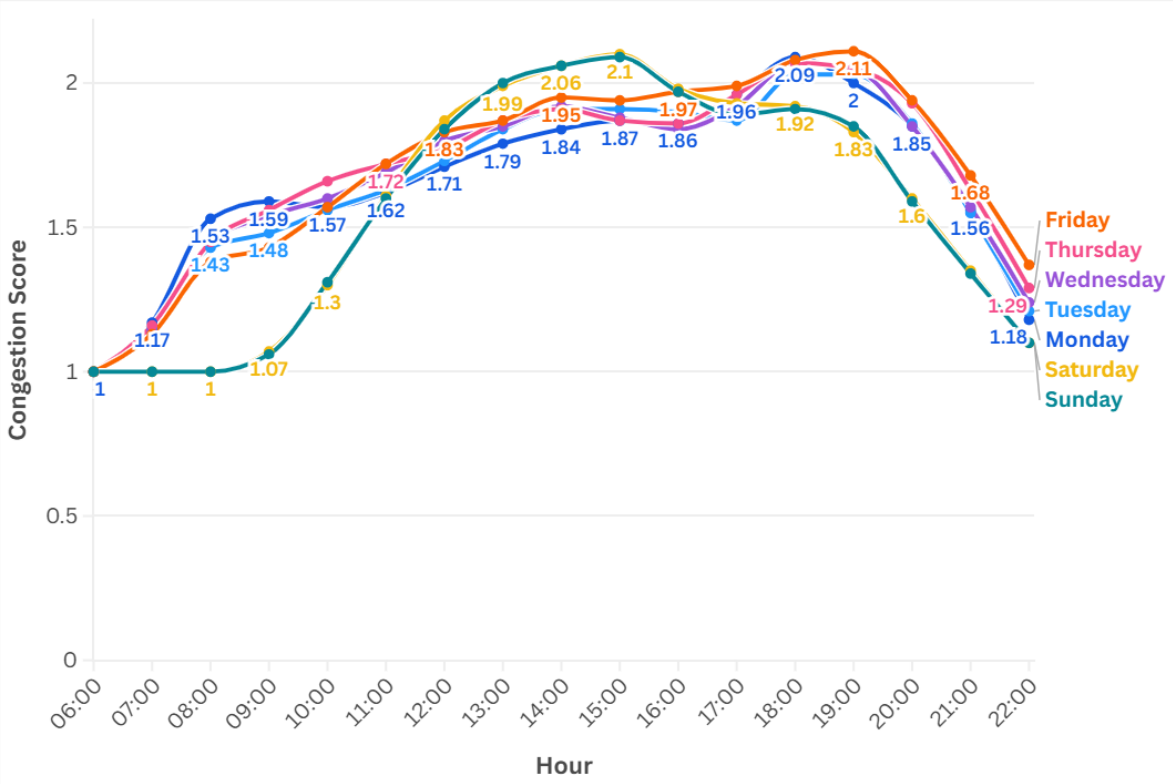




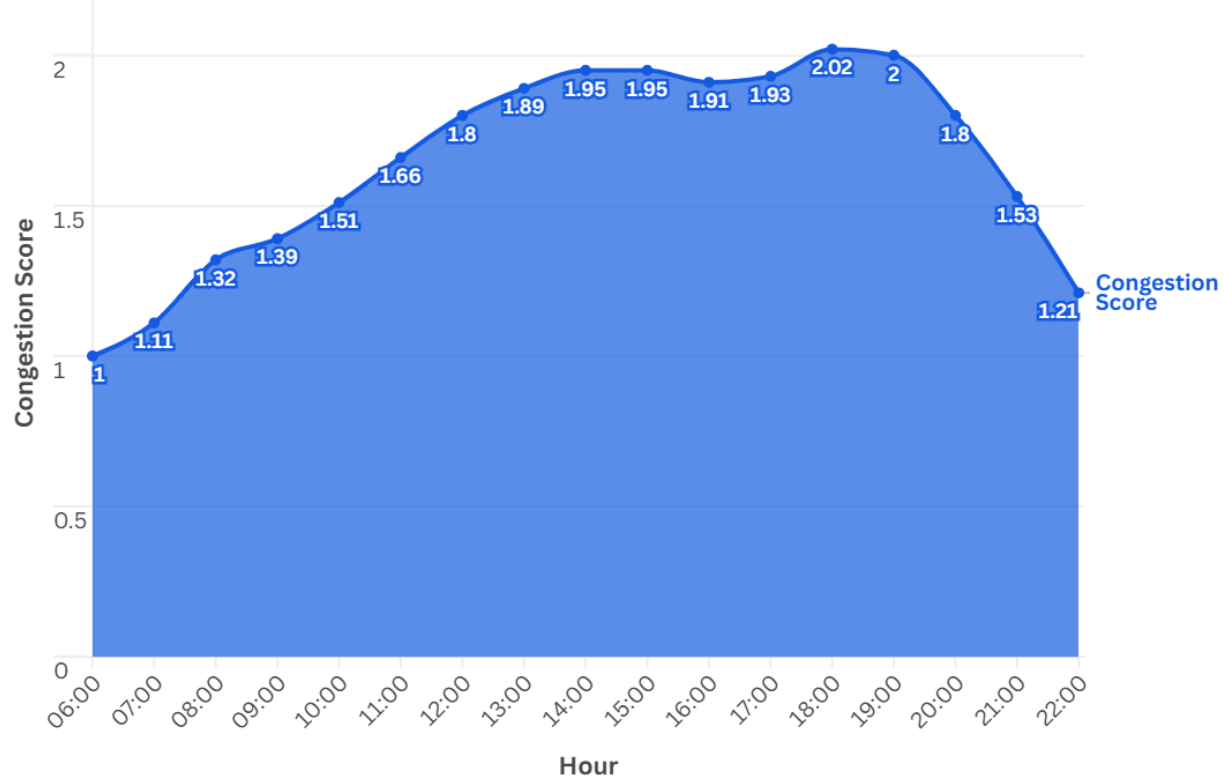


Overall and hourly traffic congestion patterns

Hourly congestion score by daily

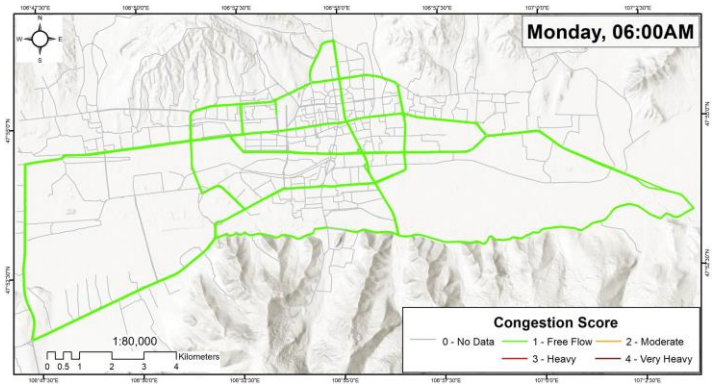


Average congestion score by hourly

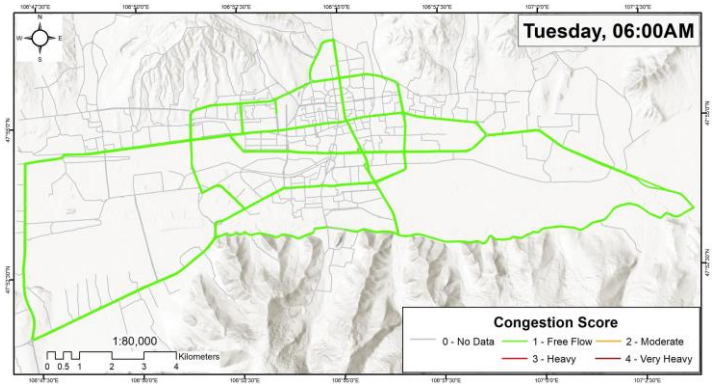


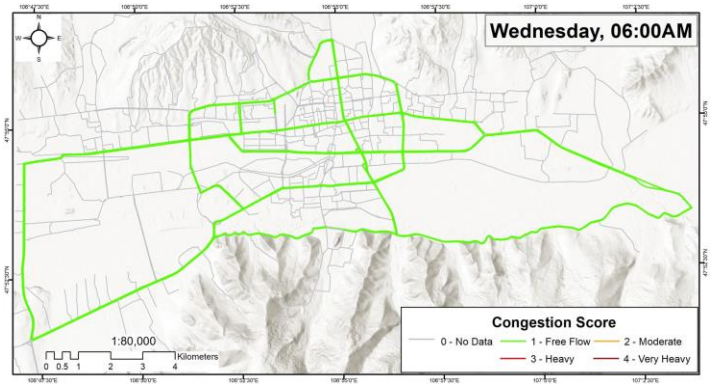
- Peak congestion hour (any time of day): **Friday 07:00 PM ≈ 2.11**
- Week days peak congestion period #1: **(08:00 AM to 02:00 PM)**
- Week days peak congestion period #2: **(05:00 PM to 07:00 PM)**
- Weekend peak congestion period: **(11:00 AM to 03:00 PM)**

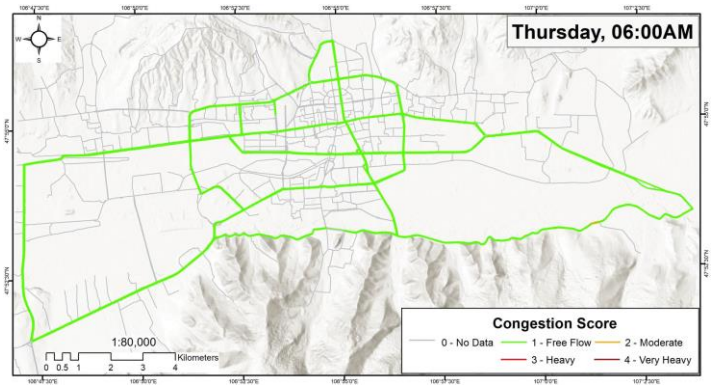
- Peak congestion hour: **6:00 PM (2.02)**
- Lowest congestion hour: **6:00 AM (1.00)**
- Daily average congestion score: **1.67**

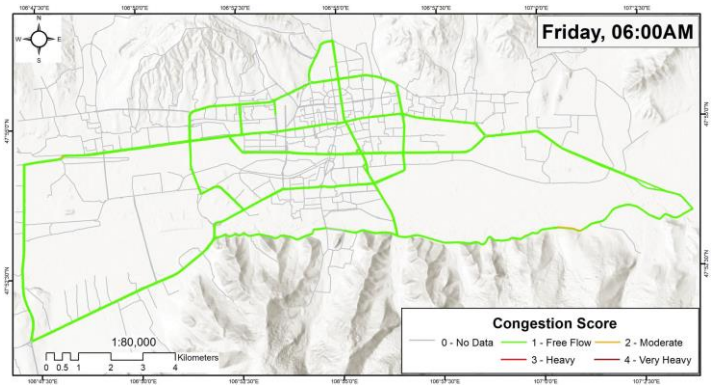


Transition of week days congestion by hourly

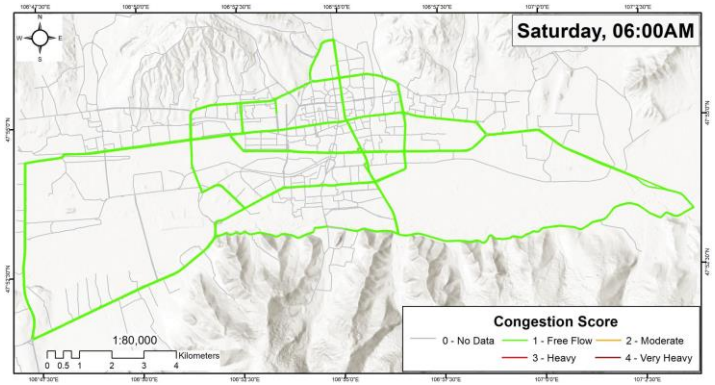


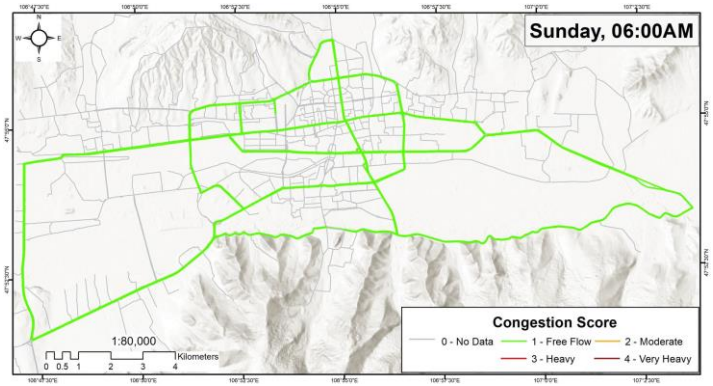






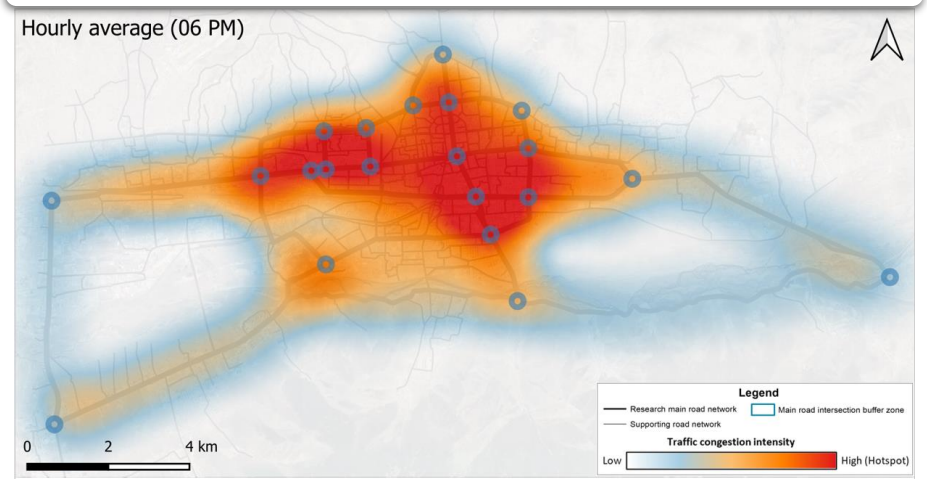
Transition of weekend days congestion by hourly



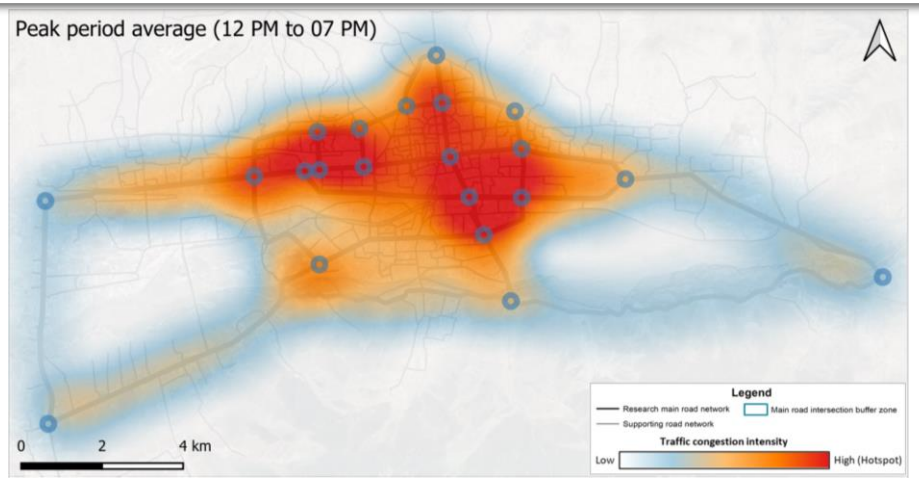


Traffic congestion hotspot and impact of major road intersections accessibility

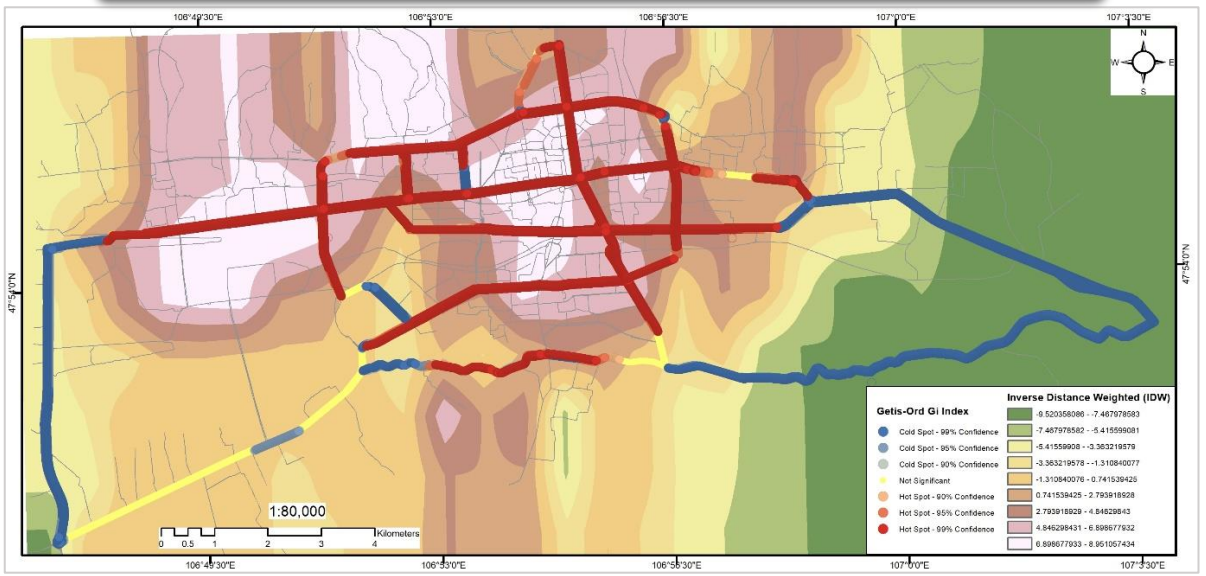
Congestion Hotspot intensity (Peak 06:00 PM)



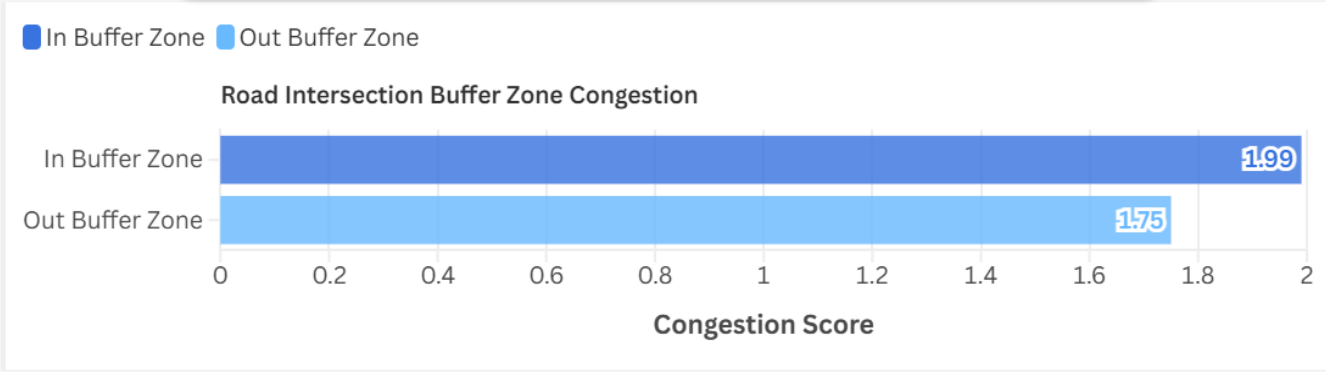
Congestion Hotspot Intensity (Peak 12:00 PM to 07:00 PM)



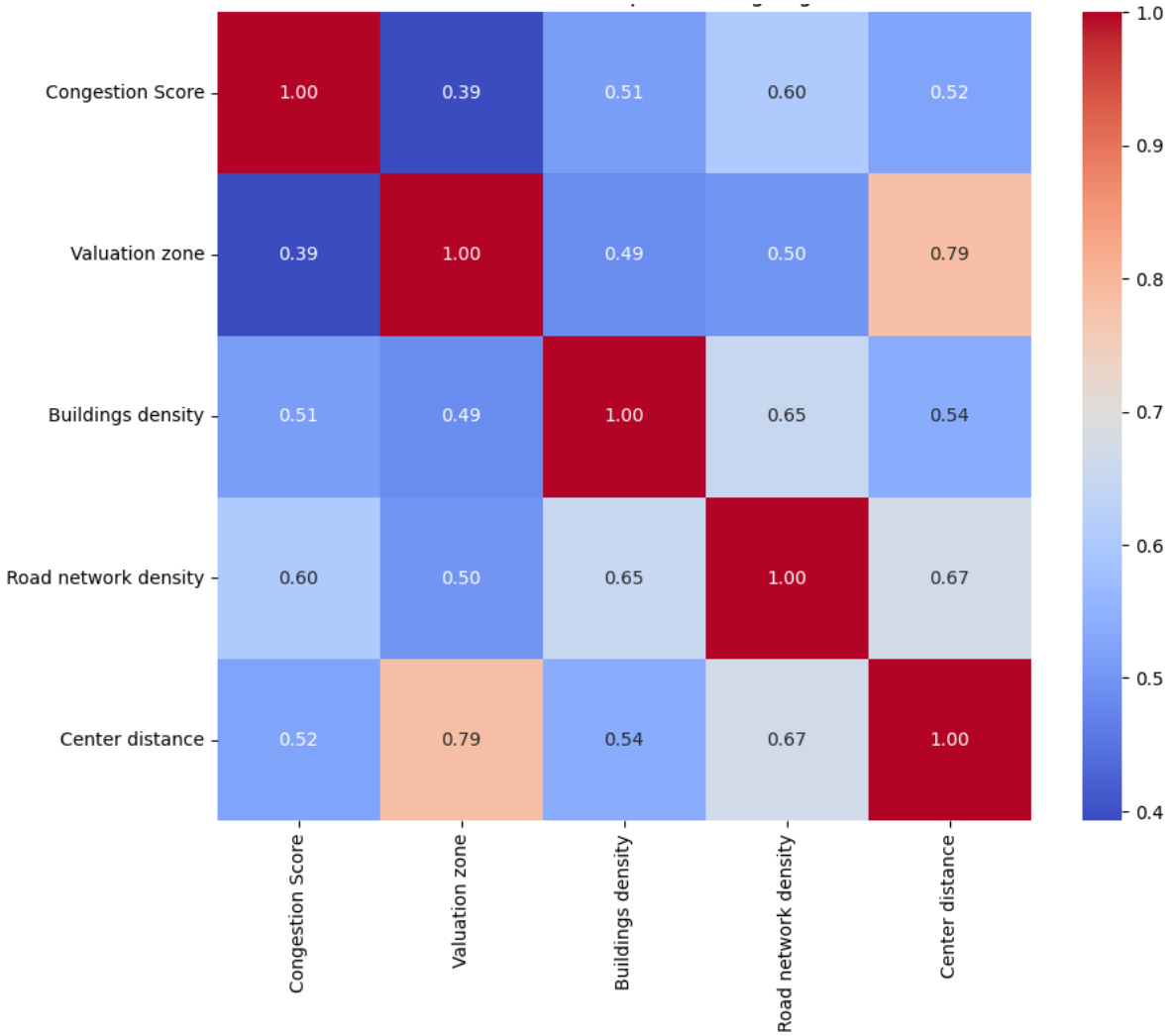
Getis-Ord Gi hotspot map (Peak 12:00 PM–07:00 PM)



Major intersections buffer zone congestion



Correlation matrix heatmap



Interpretation of the Correlation Results

Congestion score moderately correlates with:

- Road Network Density (0.60)
- Proximity to the City Center (0.52)
- Building Density (0.51)

Congestion score weakly correlates with:

- Land Valuation Zone (0.39)

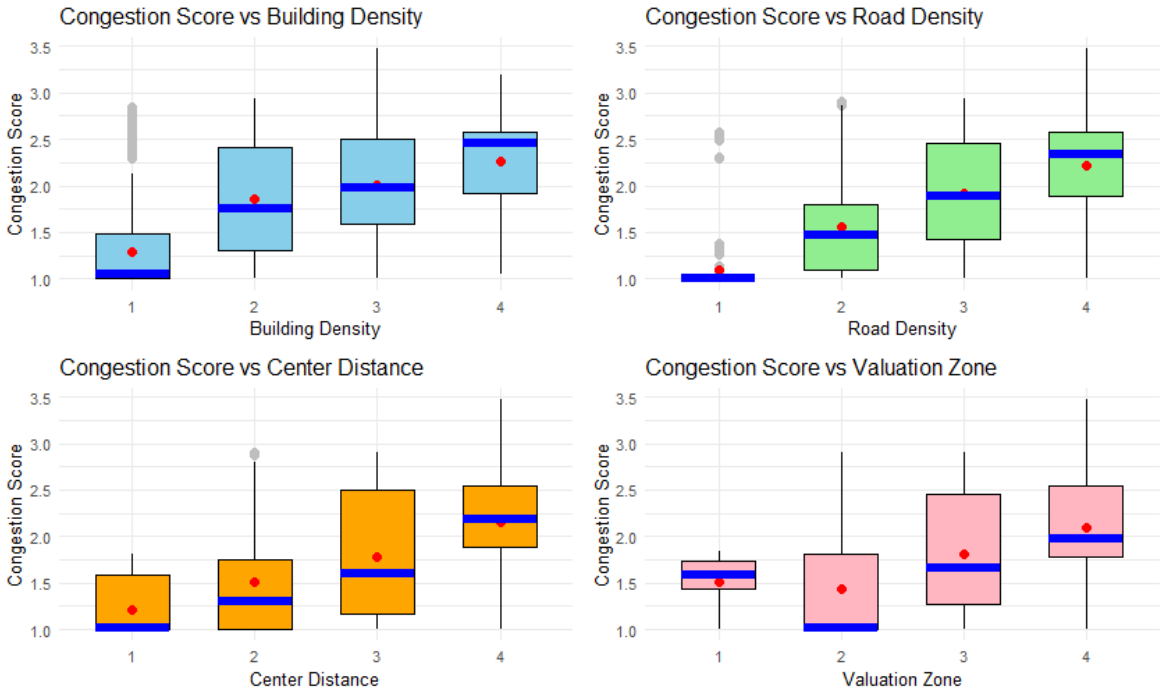
Valuation zone strongly correlates with:

- Proximity to the City Center (0.79)

Potential Multicollinearity:

Building Density ↔ Road Network Density (0.65)

Road Density ↔ Proximity to the City Center (0.67)



Linear regression (OLS) model Multicollinearity Diagnostics Table

Statistic	Value
R-squared	0.4095
Adjusted R-squared	0.4095
F-statistic	9502 (p < 2.2e−16)
Residual Standard Error	0.487
Observations	54,812
VIF Range	1.84 to 3.57 (no multicollinearity)

Linear regression (OLS) model Output Table

Predictor	Estimate	Std. Error	t-value	p-value	Significance
(Intercept)	0.651	0.007	92.91	< 2e-16	***
Building Density	0.115	0.00283	40.64	< 2e-16	***
Road Density	0.214	0.00299	71.84	< 2e-16	***
City Center Proximity	0.137	0.00372	36.74	< 2e-16	***
Land Valuation Zone	-0.035	0.00352	-9.98	< 2e-16	***

Key Factors Influencing Traffic Congestion (Regression Results)

01

Buildings Density (β=0.115)

Higher building density generates more trips and activities, leading to increased congestion.

More buildings = More people & trips

02

Road network Density (β=0.214)

Denser road networks often attract more traffic (induced demand) and create more intersections and delays, resulting in higher congestion.

Denser road network = Induced demand

03

Proximity to the city center (β=0.137)

Locations closer to the city center attract a large volume of commuting and commercial trips, increasing congestion.

Closer to the center = More commuting & trips

04

Land valuation zone (β= −0.035)

Higher land values are associated with lower traffic congestion

Low land price = Higher congestion

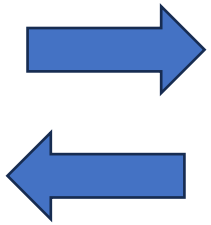
Potential explanation

- More investment in high-quality infrastructure
- Stricter traffic management policies (e.g., illegal parking controls)
- Distribution across land-use types with lower congestion scores

Summary of key findings

Spatio-temporal analysis key findings

- **Peak hour period:** 12:00–19:00
- **Peak hour:** 18:00 (Avg. Score: 2.02)
- **Most congestion day:** Friday (Avg. Score: 1.91)
- **Least congestion day:** Sunday (Avg. Score: 1.81)
- **Weekdays:** Stable congestion
- **Weekends:** Different patterns, showing unique travel behavior
- **Major Intersections impact:** High congestion near buffer zones (Avg. Score: 1.99) contributing to traffic buildup
- **Congestion by land use**: Core zones face the most pressure, especially residential and commercial areas.



Statistical analysis key findings

Key correlations:

- **Moderate positive correlation with congestion:**
  - Road Network Density (r = 0.60)
  - Proximity to the City Center (r = 0.52)
  - Building Density (r = 0.51)
- **Weak positive correlation with congestion:**
  - Land Valuation Zone (r = 0.39)
- **Other key correlations between independent variables**
  - Land Valuation Zone ↔ City Center Proximity (r = 0.79)
  - Building Density ↔ Road Network Density (r = 0.65)
  - Road Density ↔ City Center Proximity (r = 0.67)

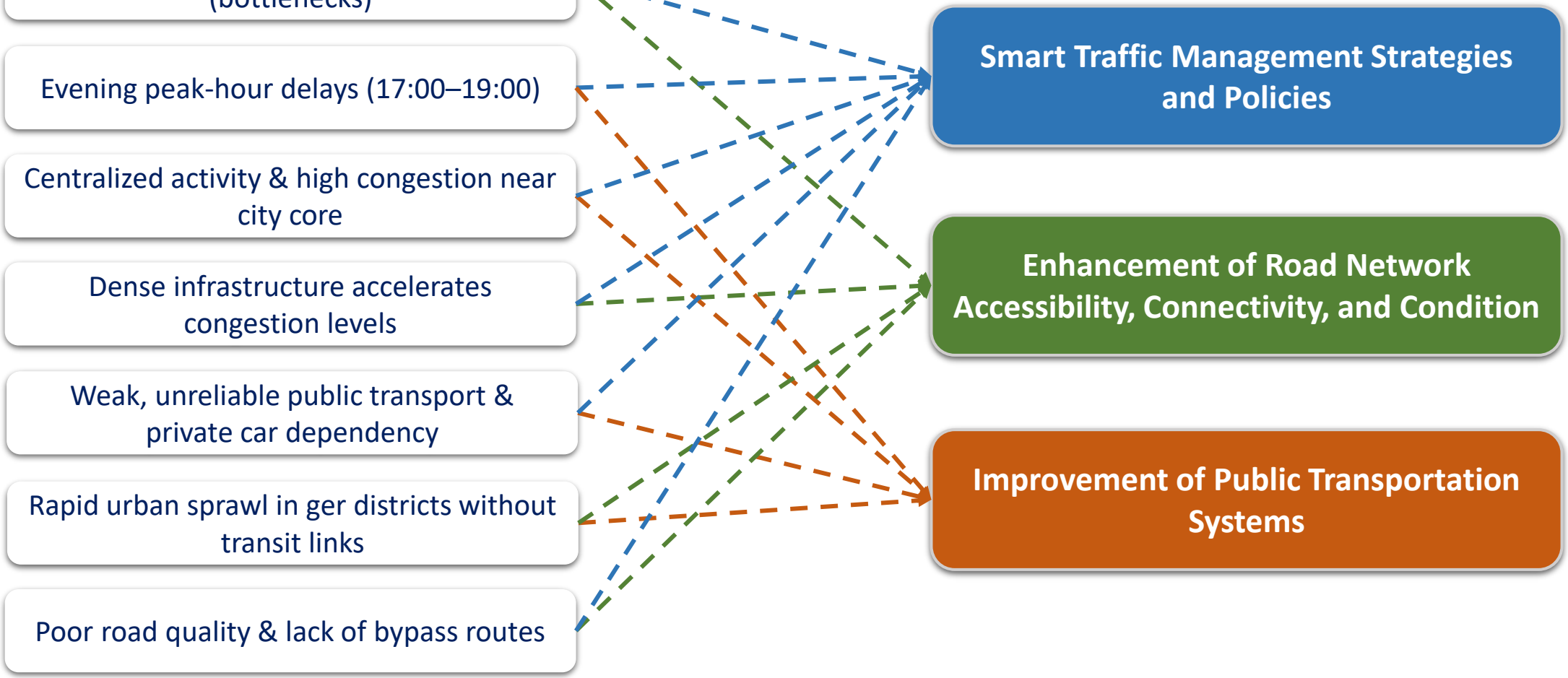
Regression model Summary:

- **$R^2 = 0.41$** Model explains 41% of variance in congestion
- **$F = 9502$, $p < 0.001$** → All predictors are statistically significant

Research key findings / Problems

- Severe congestion at intersections (bottlenecks)
- Evening peak-hour delays (17:00–19:00)
- Centralized activity & high congestion near city core
- Dense infrastructure accelerates congestion levels
- Weak, unreliable public transport & private car dependency
- Rapid urban sprawl in ger districts without transit links
- Poor road quality & lack of bypass routes

Main solution frameworks



Smart Traffic Management Strategies and Policies

	Action	Best Practices	Expected Impact	Phase/Duration
AI-based adaptive traffic signals	busiest intersections, dynamic signal optimization, real-time flow balance	Helsinki & Singapore	Reduce delays, smoother flow	Short-term
Traffic monitoring platform	GNSS, CCTV, IoT sensors, central dashboard for traffic authorities	Seoul TOPIS model & 2GIS Platform	Faster response, congestion prevention	Mid-term
Congestion peak hour specific policy	UB central zone, 17:00–19:00 peak, reinvest revenue into transit upgrades	London & Singapore ERP	Reduced peak-hour congestion	Mid-term
Incident management system	real-time detection of crashes/breakdowns, automated rerouting alerts	Amsterdam	Sustainable planning, improved governance	Long-term

Enhancement of road network accessibility, connectivity and condition

	Action	Best Practices	Expected Impact	Phase/Duration
Main intersection redesign	roundabouts, grade separation, pedestrian overpasses at top hotspots	Singapore & Beijing	Reduce local congestion hotspots	Mid-term
Road capacity enhancement	dedicated public transport lanes, signal coordination	Beijing BRT Line	Divert through-traffic, reduce inner-city load	Mid-term
Road condition & rapid repair	road maintenance reporting & quick response for potholes at priority roads	Paris & Tokyo	Reduced peak-hour congestion	Short-term
Last-mile connectivity program	micro-mobility hubs, feeder buses linking ger districts to main corridors	Copenhagen	Balanced mobility, reduced car dependency	Long-term

Improvement of Public Transportation System

	Action	Best Practices	Expected Impact	Phase/Duration
Bus priority measures	queue-jump lanes, signal pre-emption, BRT-style corridor operations	Milan & Vienna	Efficient, reliable mass transit	Mid-term
Smart fleet management	real-time GNSS monitoring, idle time reduction, driver compliance tracking	Singapore LTA	Better accessibility, reduced waiting	Short-term
Unified ticketing & MaaS platform	smart card + mobile app, integrates bus, taxi, micro-mobility	Vienna Wiener Linien & Seoul	Convenience, higher ridership	Short-term
High-frequency express bus service	ring-road & airport corridors, <5 min headway peak, limited stops	Hong Kong Airport Express model	High-capacity, sustainable urban mobility	Long-term

Integrated Conclusion

This research analyzed the **spatial and temporal patterns** of traffic congestion in Ulaanbaatar using **Google Maps based** congestion score data.

- Peak congestion occurs on **weekday afternoons**, especially between **12:00 PM and 7:00 PM**, concentrated around central intersections and dense urban zones.
- These hotspots are linked to **compact land use, high building density**, and **limited road connectivity**.

Key Findings:

- Congestion decreases with proximity to the **city center.**
- Areas with **well-connected road networks** experience less pressure.
- **Commercial and high-value land parcels** show persistent congestion, highlighting the role of urban function.
- **Regression and correlation analysis** confirm that **land use intensity, population concentration**, and **infrastructure density** are strong predictors of congestion.

Limitation Identified:

- **Key structural** and **planning challenges**, such as many major roads running along the boundaries of administrative units and districts, which becomes a **research limitation** to account for more **independent variables for congestion analysis**.

Recommendations:

- Improve **road connectivity** at major intersections and expand infrastructure in underserved areas.
- Encourage **decentralized urban development** to distribute activity more evenly.
- Integrate **land use and transport planning** using spatial data and real-time monitoring.

Google Maps' Traffic layer provides a clear and high-resolution congestion summary using color-coded roads. It's a simple also powerful tool for analysing traffic congestion and evaluating traffic policies. When combined with other source of traffic congestion data it will become a strong and evidence-based foundation for smart mobility.

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Thank you for your attention