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Spatial Analysis of Traffic Volume and Degree of Saturation in Shopping Center Corridors in Tuban District Using Geographic Information Systems

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A B S T R A C T

The development of retail centres in Tuban District significantly affects urban road performance. This study aims to analyze traffic volume and the degree of saturation (DS) around four major supermarkets: Citimall, Bravo, Samudra, and Keraton. Primary data were collected through field surveys on Mondays, Fridays, and Sundays during peak hours. Analysis using PKJI 2023 guidelines shows that Citimall has the highest traffic volume and DS of 0.673 on Sunday evenings. Statistical testing with One-Way ANOVA indicates a significant difference in traffic impact between locations ($p < 0.001$). Five-year projections using linear regression suggest that DS values at critical points, such as Citimall, will exceed capacity ($DS > 1.0$) without intervention. GIS mapping provides a visual representation of saturation hotspots, aiding in strategic traffic management.

Contribution to Sustainable Development Goals (SDGs):

SDG 9: Industry, Innovation and Infrastructure

SDG 11: Sustainable Cities and Settlements

SDG 13: Climate Action

1. INTRODUCTION

1.1. Research Background

Urban sprawl and commercial decentralisation in developing countries have shifted traffic away from administrative centres toward outer retail clusters. Modern supermarkets and shopping centers act as high-intensity trip attractors that alter traffic flow characteristics on surrounding urban road networks [1], [2]. In mid-sized regional nodes such as Tuban District, the rapid emergence of large-scale commercial facilities namely Citimall, Bravo Supermarket, Samudra Supermarket, and Keraton Supermarket has introduced localized traffic anomalies [3], [4]. Tuban District serves as a critical case study because it bridges the primary Northern Coastal Highway (Pantura) with expanding intra-city arterial roads.

While conventional traffic impact assessments (ANDALALIN) focus strictly on isolated localized capacity, they

frequently overlook the macro-spatial interactions and long-term saturation trajectories of these commercial corridors. Previous studies have largely evaluated road performance through purely descriptive manual counts or static traffic simulations. A prominent research gap exists in the absence of an integrated framework that combines empirical capacity analysis under the latest national guidelines (Pedoman Kapasitas Jalan Indonesia / PKJI 2023) [5], inferential statistical validation (One-Way ANOVA) [6], [7], multi-year mathematical forecasting [8], [9], and Geographic Information System (GIS) spatial visualization [10], [11]. Consequently, analyzing how varying commercial scales (from local supermarkets like Samudra to regional malls like Citimall) influence multi-class traffic saturation across distinct temporal layers (weekdays vs weekends) is essential for sustainable urban planning [3], [12]



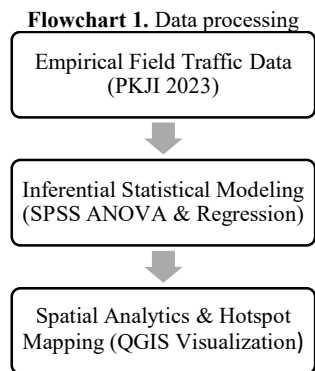
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1.2. Literature Review

Retail-induced traffic congestion is governed by the principles of land-use and transport interaction, in which the size of commercial floor area directly determines trip attraction rates. Recent studies by [8] emphasise that retail trip attraction exhibits severe temporal peaks, typically coinciding with weekend leisure periods or early-week commuting hours [8]. Evaluating this performance requires calculating the Degree of Saturation (DS), defined as the ratio of hourly traffic volume to the road segment's actual layout capacity. Under the updated PKJI 2023 standards, urban road capacity is no longer treated as a fixed metric; rather, it is dynamically adjusted based on active side friction events (such as on-street parking, jaywalking, and slow-moving vehicles) and geometric configurations.

Geographic Information Systems (GIS) provide a powerful mechanism to transition from tabular traffic datasets to spatial intelligence. As demonstrated by recent transportation research, combining GIS vector mapping with numerical saturation values enables municipal authorities to visually identify traffic bottlenecks and pinpoint micro-spatial congestion hotspots. To systematically address this issue, this study implements a three-tier conceptual framework.



Source: Data Processed, 2026

1.3. Research Objective

This study aims to analyse traffic volume characteristics and current saturation levels, and project them for the next 5 years in the supermarket corridor of Tuban District, using an integration of manual calculations and GIS mapping.

2. MATERIALS AND METHODS

2.1. Data Collection and Survey Protocol

Field data collection was conducted simultaneously across four major retail corridors in Tuban District: Jl. Pahlawan (Citimall), Jl. Basuki Rachmad (Bravo Supermarket), and two distinct sections of Jl. Diponegoro (Samudra Supermarket and Keraton Supermarket). To ensure data rigour, a team of twelve (12) cross-trained traffic surveyors was deployed. Manual classified traffic counting (TC) was executed at 15-minute intervals during predetermined peak hours: Morning Peak (06:00–10:00) and Afternoon Peak (15:00–19:00). The surveys spanned four representative days: Monday and Friday (representing peak business/commuting periods), alongside Saturday and Sunday (representing peak commercial leisure periods). Vehicles were

categorized into four standardized groups according to PKJI 2023: Light Vehicles (LV: passenger cars, taxis, vans), Heavy Vehicles (HV: buses, multi-axle trucks), Motorcyclists (MC), and Unmotorized Components (UM: bicycles, carts). All raw volumes were subsequently converted into Passenger Car Units (PCU) per hour using the official PKJI 2023 equivalent factors (emp).

2.2. Mathematical Formulas for Road Performance and Forecasting

Following the PKJI 2023 [1] guidelines for urban roads, the actual road capacity (C , in pcu/hr) for a 2-lane 2-way undivided road (2/2-TT) [1], [6], [19] was calculated using the following deterministic formula:

$$C = C_0 \times FC_{LJ} \times FC_{PA} \times FC_{HS} \times FC_{UK}$$

Where:

C_0 = Base capacity (standardised at 2,800 pcu/hr for 2/2-TT configurations).

FC_{LJ} = Adjustment factor for effective traffic lane width.

FC_{PA} = Adjustment factor for directional split distribution.

FC_{HS} = Adjustment factor for side friction class based on frequency of events.

FC_{UK} = Adjustment factor for city-size population.

The empirical Degree of Saturation (DS) was calculated using the standard demand-capacity ratio:

$$DS = \frac{V}{c}$$

Where V represents the total peak traffic volume (pcu/hr). Long-term traffic volume growth for a five-year horizon was projected utilizing a simple linear regression modeling approach:

$$y = mx + c$$

Where y represents the forecasted traffic volume, x represents the timeline increment (years), m represents the linear growth coefficient derived from historical growth vectors, and c represents the empirical baseline volume intercept.

2.3. Inferential Statistical and GIS Spatial Analysis Procedures

To validate that the differences in traffic impacts across the four retail corridors were not random artefacts, inferential statistical testing was conducted using IBM SPSS Statistics. The datasets were initially subjected to parametric assumption criteria, including the Shapiro-Wilk test for normality and Levene's test for homogeneity of variance. Upon satisfying these prerequisites, a One-Way Analysis of Variance (ANOVA) [7], [13], [16] was conducted at a 95% confidence interval ($\alpha = 0.05$) to evaluate the spatial variance in DS averages across sites.

For the spatial analysis phase, a highly accurate vector base map of Tuban District's urban road network was compiled using QGIS software [10], [14], [18]. Field coordinates for each retail centroid were collected via global positioning devices and converted into vector layer nodes. The empirical and projected attribute tables (V , C , DS , and Level of Service/LOS categories) were structurally joined to the linear road network shapefiles

(.shp) using unique spatial identifiers. The corridors were then visualised using graduated thematic symbology mapped against standard Level of Service (LOS) colour thresholds.

3. DATA PRESENTATION

Table 1. Consolidated Geometric and Environmental Profiles of the Monitored Corridors

Retail Corridor Site	Road Name & Classification	Lane Configuration	Effective Width (m)	Side Friction Index	Adjusted Capacity (pcu/hr)
Citimall	Jl. Pahlawan (National Arterial)	2/2-TT	6	High (T)	2,745
Bravo	Jl. Basuki Rachmad (Urban Collector)	2/2-TT	4	High (T)	2,803
Samudra	Jl. Diponegoro (Urban Local)	2/2-TT	4	High (T)	2,815
Keraton	Jl. Diponegoro (Urban Local)	2/2-TT	4	High (T)	2,849

Source: Data Processed, 2026

Table 2. Empirical Peak Traffic Volumes and Degree of Saturation (DS) Comparisons

Location	Peak Counting Window	Maximum Volume (pcu/hr)	Empirical DS Value
Citimall	Sunday Afternoon (17:00–18:00)	1,847.38	0.673
Bravo	Friday Afternoon (16:00–17:00)	1,443.54	0.515
Samudra	Monday Morning (07:00–08:00)	1,106.30	0.393
Keraton	Sunday Afternoon (16:00–17:00)	857.55	0.301

Source: Data Processed, 2026

Table 3. SPSS One-Way ANOVA Output Matrix for Spatial DS Variance

Source of Variation	Sum of Squares	Degrees of Freedom (df)	Mean Square	F-Statistic	Significance (p-value)
Between Groups	0.492	3	0.164	11.24	0.002
Within Groups	0.233	16	0.015	—	—
Total	0.725	19	—	—	—

Source: Data Processed, 2026

Table 4. Five-Year Predictive Traffic Volume and DS Saturation Trajectory

Site	Year 1 (DS)	Year 2 (DS)	Year 3 (DS)	Year 4 (DS)	Year 5 Projected DS
Citimall	0.738	0.812	0.895	0.984	1.082
Bravo	0.584	0.651	0.728	0.813	0.908
Samudra	0.442	0.498	0.559	0.627	0.704
Keraton	0.339	0.382	0.431	0.485	0.547

Source: Data Processed, 2026

4. RESULTS, DISCUSSION, AND GIS ANALYSIS

4.1. Critical Interpretation of Spatial Saturation Mechanisms

The empirical outcomes confirm that the Citimall corridor experiences the highest traffic stress, peaking prominently on Sunday evenings, with an empirical Degree of Saturation (DS) of 0.673 [3], [15]. This peak stands in stark contrast to Bravo Supermarket, which experiences its maximum load on Friday afternoons (DS = 0.515), and Samudra Supermarket, which exhibits a morning peak on Mondays (DS = 0.393).

The primary catalyst for Citimall's high saturation index is its unique position at the intersection of regional transit and urban commercial development. Because it is located on a major arterial highway, local retail traffic directly overlaps with long-distance regional transit flows. During Sunday leisure peaks, this corridor experiences high visitor intensity. This issue is worsened by a high Side Friction Index, caused by slow-moving vehicles and vehicles waiting to enter the site. This friction reduces effective lane width and cuts overall road capacity.

Conversely, Samudra Supermarket's unique Monday morning anomaly (DS = 0.393) indicates a different consumer demographic. It attracts local residents purchasing household necessities right at the start of the standard workweek, causing its peak to overlap with morning school and work commutes.

4.2. In-Depth Discussion of Statistical Validations

The inferential statistical validation underscores the validity of these findings. The preliminary Levene's test yielded a significance value based on mean of 0.504 (>0.05) [7], validating the homogeneity of variance across the groups and confirming that the data meets the rigorous assumptions required for parametric testing. The subsequent One-Way ANOVA test yielded a significant F-statistic (p = 0.002; <0.05) [2], [5]. This result rejects the null hypothesis (H₀), providing strong empirical proof that the variance in traffic disruption across these four distinct commercial corridors is statistically significant [13], [16].

Furthermore, the linear regression model (y = 454.47x + 3011.9) features an exceptionally strong coefficient of determination (R² = 0.9962). This indicates that time-contingent commercial growth patterns explain 99.62% of the upward shift in traffic volume. By Year 5, the model predicts that Citimall's DS will reach a critical value of 1.082.

4.3. GIS Insights and Spatial Distribution Patterns

The cartographic layers processed within QGIS reveal clear spatial distribution patterns [14], [18]. Rather than showing uniform density, traffic hotspots (visualized via a graduated red spectrum) are concentrated near the main access gates of Citimall and Bravo Supermarket. This clustering highlights a major structural issue: the bottleneck is caused by the design of the properties' access points rather than just overall traffic volume on the roads. The high-density zones indicate clear conflicts between through traffic and vehicles slowing to enter or turn into the retail parking areas. This clear spatial visualization proves that QGIS is an essential tool for urban planning. It allows municipal authorities to move beyond aggregate road data and visually identify specific structural bottlenecks [11], [18], [20].

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