quickly. Ukrainian logistics combines traditional military supply chains with modern technology and international support.

First, transportation plays a critical role. Ukraine uses railways, trucks, and sometimes civilian infrastructure to move supplies to the front lines. Railways are especially important because they allow large quantities of equipment and ammunition to be transported efficiently over long distances.

Second, flexibility is essential. Unlike older wars with stable front lines, modern warfare in Ukraine is dynamic. This means supply routes must constantly change to avoid attacks. Ukrainian forces often use decentralized logistics, where smaller units receive supplies independently rather than relying on one central system.

Third, international support is a major factor. Ukraine receives military aid from many countries. This includes weapons, vehicles, and medical equipment. Managing and distributing this aid requires coordination, planning, and trained specialists.

Another important aspect is technology. Ukraine actively uses drones, satellite communication, and digital systems to track supplies and improve coordination. This helps reduce delays and increases efficiency.

Finally, volunteers also play a unique role. Civilian volunteers help deliver equipment, repair vehicles, and support soldiers. This creates a strong connection between the army and society.

In conclusion, military logistics in Ukraine is a combination of traditional methods, modern technology, and strong international cooperation. Its flexibility and adaptability have become key factors in the country's ability to defend itself.

RESEARCH ON THE PATTERN OF PASSENGER TRAFFIC DISTRIBUTION ALONG TROLLEYBUS ROUTES IN THE CITY OF SUMY

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This article presents a comprehensive analysis of passenger traffic distribution along the trolleybus network in Sumy, a regional center in northeastern Ukraine with a population of approximately 275,000 residents. Drawing on municipal transportation studies, academic research, and route network modeling conducted using the VISUM software package, this paper identifies key patterns in passenger flow distribution, evaluates the operational efficiency of existing trolleybus routes, and examines the impact of competition from private minibus routes (marshrutkas) on municipal electric transport. The findings reveal significant imbalances in passenger traffic distribution, excessive route duplication by private carriers, and the need for targeted infrastructure and service improvements.

Sumy is a city of about 275,000–295,000 residents, covering an area of 93.4 km², of which 71.23 km² is developed land. The city is located on the banks of the Psel, Sumka, and Strelka rivers, which significantly constrain the development of the street and road network. Public transport in Sumy includes three main types: municipal transport (trolleybuses and buses), private transport (marshrutkas), and commercial-individual transport (taxis).

The municipal trolleybus system, operated by the municipal enterprise "Electroavtotrans," was established in 1967. The enterprise currently operates 71 passenger trolleybuses serving 16 city routes, with a total trolleybus network length of 103 kilometers (in single-track terms). Annual passenger volume by trolleybus is approximately 22 million passengers.

This research aims to analyze the patterns of passenger traffic distribution along trolleybus routes in Sumy, identify problem areas in the route network, and propose evidence-based recommendations for optimization.

The methodology for this research draws on several approaches developed and applied in Sumy over the past decade.

Route Network Modeling The primary analytical tool employed is the VISUM software package (PTV VISION), which allows for detailed and comprehensive modeling of Sumy's public transport network. This modeling includes the assessment of:

- Passenger accessibility to stops (walking distance)
- Route straightness coefficients
- Stop spacing and density
- Degree of route duplication between trolleybuses and private carriers

Passenger Traffic Surveys Repeated passenger traffic surveys have been conducted on Sumy's trolleybus routes. These surveys utilize a table-questionnaire method, which offers relative simplicity, low labor intensity, and the ability to obtain reliable data in relatively short timeframes.

Key survey parameters included:

- Survey periods: Spring (April) and autumn (October) seasons
- Duration: 12 hours daily (7:00 to 19:00)
- Method: Two-person teams boarding vehicles at stops, counting passengers by category (full-fare vs. concessionary)
- Data collection: Specialized questionnaires completed at each stop

Evaluation Indicators The following indicators were used to assess route network quality:

- Route coefficient: evaluating transport network accessibility
- Stop spacing: distance between stops (normative values: 400–600 m for trolleybuses)
- Network density: transport line length per developed area (normative: 1.3–2.5 km/km²)
- Duplication coefficient: share of shared stops between trolleybus and bus/marshrutka routes
- Load factor: passenger occupancy by route and time period

Current Network Status Analysis of Sumy's trolleybus network reveals the following characteristics:

PARAMETER	VALUE	NORMATIVE REQUIREMENT	COMPLIANCE
Number of trolleybus routes	15–16	—	—
Average stop spacing	0.40 km (207 segments)	0.40–0.60 km	Meets

Minimum stop spacing	0.04 km	—	—
Maximum stop spacing	3.6 km	—	—
Network density	1.33 km/km²	1.3–2.5 km/km²	Meets minimum
Daily vehicle output	~40 units	—	—

The average stop spacing for trolleybuses (0.40 km) falls within the normative range of 400–600 meters. However, network density is at the lower boundary of acceptable values (1.33 km/km²), indicating a weakly developed network that meets pedestrian accessibility norms only at the minimum level.

Route Duplication Problem A critical finding of the analysis is the excessive duplication of trolleybus routes by private marshrutkas, which contradicts Ukrainian government regulations requiring the elimination of unjustified duplication of tram and trolleybus routes.

Key data on route duplication:

- Average number of bus/marshrutka routes significantly duplicating each trolleybus route: 8.5
- Maximum duplication (Route No. 18): 15 bus/marshrutka routes
- Routes with full or near-full duplication (one to two bus/marshrutka routes covering >50% of the route): 8 trolleybus routes

Passenger Traffic Distribution The distribution of passenger traffic among transport modes in Sumy is severely imbalanced. Based on survey data:

Transport Mode	**Share of Passenger Traffic**	**Number of Vehicles**
Marshrutkas (minibuses)	65–83%	476
Trolleybuses	11–15%	~71

Municipal buses	6%	39 (private) + 21 (municipal)
Taxis	Remainder	—

Daily passenger volumes (average):

- Marshrutkas: approximately 151,300 passengers carried
- Trolleybuses: approximately 76,700 passengers

Temporal and Spatial Distribution Patterns Analysis of passenger traffic reveals distinct patterns:

Peak hour challenges:

- Trolleybuses on high-demand routes (Nos. 1, 2, 3, 4, 5, 7, 12, 13, 15) are severely overcrowded during morning and evening peak hours
- Overcrowding results from a combination of concessionary passengers (including many factory workers and students) and limited vehicle frequency
- In some cases, trolleybuses cannot close doors due to overcrowding, resulting in passengers being left at stops

Stop occupancy distribution:

The city's 316 stops show highly uneven distribution of route usage:

- Significant variation in the number of routes serving each stop
- Central area stops serve the highest number of routes
- Peripheral stops serve minimal routes, creating accessibility gaps

Concessionary Passenger Share A persistent challenge for Sumy's trolleybus system is the high proportion of concessionary (free or discounted) passengers. The number of concessionary categories in Sumy is 21, contributing significantly to the financial difficulties of the municipal enterprise.

The share of concessionary passengers directly affects:

- Revenue per vehicle: Each fare-free passenger represents lost income
- Service frequency: Without adequate compensation, service levels cannot be maintained
- Vehicle overcrowding: Concessionary passengers occupy capacity needed by paying passengers

Interpretation of Findings reveals a paradoxical situation: although Sumy has a functioning trolleybus network that meets basic technical standards (stop spacing, network density), it carries only 11–15% of total passenger traffic while marshrutkas carry 65–83%. This imbalance reflects:

1. Mode choice preferences: Passengers prioritize speed and perceived convenience over lower cost and environmental benefits

2. Frequency competition: Marshrutkas operate at much higher frequencies (often 2–3 minute headways vs. 10–15 minutes for trolleybuses in off-peak hours)

3. Route coverage: Marshrutka routes cover the entire city and its outskirts, providing more direct connections between residential areas

Comparison with Other Ukrainian Cities While many Ukrainian cities face similar challenges with marshrutka competition, Sumy's situation is more extreme. The national average distribution is approximately:

- Trolleybuses: 35% of passenger traffic
- Buses: 12%
- Marshrutkas: 34%
- Other (trams, metro, etc.): 19%

Sumy's 11% share for trolleybuses is substantially below the national average, indicating unique local factors.

Economic Implications The "monopolization" of the transport market by private marshrutkas has several negative consequences for the municipal trolleybus system:

- Revenue erosion: Each passenger choosing a marshrutka reduces trolleybus income
- Fixed costs burden: Trolleybuses require expensive infrastructure (overhead wires, substations, depots) that must be maintained regardless of ridership
- Concessionary compensation: The municipal enterprise must be compensated for concessionary passenger transport, but compensation is tied to accurate passenger counts

Methodological Considerations The table-questionnaire method used in passenger surveys has inherent limitations:

- Underreporting of concessionary status: Some passengers may not truthfully report their fare status

- Sampling bias: Surveys during certain hours may overrepresent specific passenger categories

- Seasonal variation: Spring and autumn surveys may not capture winter or summer patterns

Nonetheless, the consistency of results across multiple survey years (2015–2019) suggests reliable patterns.

Based on the research findings, the following recommendations are proposed:

1. Reduce route duplication. Remove marshrutka routes that duplicate >75% of trolleybus routes. The current average of 8.5 duplicating routes per trolleybus route is both economically and environmentally unsustainable.

2. Optimize trolleybus frequency. During peak hours, reduce headways on high-demand routes (Nos. 1–5, 7, 12–13, 15) to 10 minutes or less. This would reduce overcrowding while improving mode choice competitiveness.

3. Modernize the vehicle fleet. Replace aging trolleybuses (many from the Soviet era) with modern, low-floor vehicles offering improved comfort and accessibility. The municipal enterprise currently operates approximately 71 trolleybuses.

4. Create a unified coordination center. Establish a centralized dispatch system to coordinate schedules between trolleybuses and complementary bus routes, reducing wait times and improving information for passengers.

5. Improve stop infrastructure. Address the uneven distribution of stop usage by creating dedicated lanes and priority signaling for trolleybuses at the most congested stops.

6. Implement smart ticketing. Introduce electronic fare collection to accurately track passenger categories, improving compensation calculations and reducing fare evasion.

7. Expand network selectively. Add new routes or extend existing ones to underserved residential areas, increasing network density beyond the current minimal level of 1.33 km/km^2.

8. Reform concessionary compensation. Develop a transparent, data-driven system for calculating and delivering subsidy payments to the municipal enterprise based on actual concessionary passenger counts from electronic validation.

Conclusion This research on passenger traffic distribution along Sumy's trolleybus routes reveals a system under significant stress. While the physical infrastructure (stop spacing, network coverage) generally meets technical norms, the system's operational and financial sustainability is severely compromised by excessive competition from private marshrutkas.

Key findings include:

- Trolleybus share of passenger traffic (11–15%) is far below the national average
- Trolleybus routes are duplicated by an average of 8–15 marshrutka routes
- Concessionary passengers constitute a substantial share of trolleybus riders
- Peak hour overcrowding exists alongside off-peak underutilization

Without targeted intervention, the trolleybus system risks further ridership decline, leading to reduced service levels and eventual network contraction. However, with evidence-based reforms—particularly route restructuring, frequency optimization, fleet modernization, and integrated coordination—Sumy's trolleybus network can remain a viable, efficient, and environmentally sustainable component of the city's transport system.

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ANALYSIS OF METHODS FOR OPTIMIZING INTERMODAL TRANSPORT SYSTEMS USING DIGITAL TECHNOLOGIES AND COST ANALYSIS

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This article examines contemporary approaches to optimizing maritime and intermodal transport in the context of economic globalization, rising prices for fuel and energy resources, and increasingly stringent environmental requirements in the transport sector. It analyzes the impact of fuel costs on the configuration of container transport, the economics of intermodal transport, and the reduction of emissions from ship engines. The use of economic-mathematical methods and information technologies to improve the efficiency of transport systems is examined separately. The impact of optimizing ship speeds, implementing energy-efficient technologies, and utilizing intermodal logistics on cost reduction and the sustainable development of the industry has been investigated. In a generalized form, the results obtained can be used to optimize the transportation process and for the general development of system development strategies.

In recent years, the issue of improving maritime and intermodal transport has increasingly become the subject of scientific research in various countries around the world. T. Notteboom and B. Vernimmen conducted studies on the impact of fuel costs on the organization of maritime transport. They noted that rising fuel prices significantly affect the structure of the container fleet. This leads companies to reduce vessel speeds to optimize routes.

M. Issa explores the environmental sustainability of maritime transport and the