СЕКЦІЯ
ПИТАННЯ СУЧАСНОГО РОЗВИТКУ ТРАНСПОРТНИХ ТЕХНОЛОГІЙ.
НАУКОВІ ЗАСАДИ ІЗ ЗАБЕЗПЕЧЕННЯ ОРГАНІЗАЦІЇ ТА БЕЗПЕКИ ДОРОЖНЬОГО РУХУ.
ТРАНСПОРТНА ЛОГІСТИКА - ВИКЛИК СУЧАСНОСТІ.

MODELING OF TRAFFIC FLOW DISTRIBUTION AT ROAD NETWORK NODES

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Traffic flow management at city intersections directly influences transportation efficiency, road safety, and the environmental condition of urban and suburban areas. Under conditions of increasing traffic volumes and urbanization, developing mathematical models for analyzing and optimizing transportation distribution is crucial for creating efficient transport infrastructure [1].

The purpose of this study is to develop a mathematical model for traffic flow distribution at intersections to enhance traffic management efficiency and optimize the transportation system. The proposed model is based on a matrix approach for determining traffic flow transition probabilities at road network nodes. A factor coefficient method is applied to account for variations in traffic intensity by days of the week.

The model enables evaluating intersection load, forecasting traffic intensity changes, and determining optimal traffic light control modes. In addition to basic distribution aspects, the study examines the interaction of traffic flows with external factors such as weather conditions, accidents, and seasonal fluctuations.

Key components of the model include traffic flow forecasting depending on various factors, traffic signal cycle optimization to reduce congestion, and load assessment of specific traffic nodes.

The advantage of the model lies in the use of adaptive algorithms for real-time traffic flow management [2].

The following mathematical methods are applied for traffic analysis: graph models to represent the transport network as nodes and edges for efficient direction and corridor capacity analysis; matrix-based flow distribution analysis, which considers vehicle transition probabilities between movement directions [2].

Changes in traffic intensity may be both predictable and spontaneous. Mathematical models allow not only forecasting future changes but also identifying key patterns of flow redistribution within urban areas.

Key factors affecting traffic intensity include: time of day (morning/evening peak hours); day of the week (weekdays show higher intensity than weekends); seasonal factors (increased flow during tourism season); weather conditions (rain, snow, ice reduce average speed); and accidents (road incidents can cause serious traffic delays).

Adaptive traffic control methods include both programmed and program-adaptive approaches. The main objective is to ensure dynamic optimization of traffic flows at road network nodes using flexible and self-learning algorithms. This improves traffic efficiency, minimizes delays, and enhances the overall road network capacity.

For analyzing real traffic flows, a complex X-shaped intersection at Valentynivska Street and Akademika Pavlova Street in Kharkiv was selected. This intersection has 12 traffic directions (Figure 1).

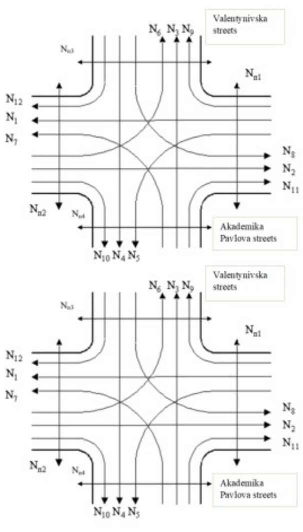


Figure 1 – Scheme of the X-shaped intersection at

Valentynivska and Akademika Pavlova Streets.

Measured inbound traffic intensity ranged from 100 to 500 vehicles/hour. Traffic composition: passenger cars – 70%; trucks – 20%; public transport – 10%.

Traffic flow intensity analysis

The traffic distribution matrix describing vehicle movement through the intersection is defined as:

$$y = P \cdot x \tag{1}$$

Where: x – input vector of flow intensities (from each direction); P – matrix of transition probabilities (likelihood of movement from one direction to others); y – output vector of flows (after the intersection).

Matrix multiplication is used to compute output flows.

General model of traffic distribution at a network node:

$$\Lambda_{вих} = A\Lambda_{вх} \tag{2}$$

where : $A = \| P^{j}{}_{2i-1} \|^{n}{}_{n}$ - traffic distribution matrix;

$\Lambda_{вих} = \| \lambda_2; \lambda_4; \ldots \lambda_{2i} \|^{T}{}_{n}$ - output flow vector (even directions)

$\Lambda_{вх} = \| \lambda_1; \lambda_3; \ldots \lambda_{2i-1} \|^{T}{}_{n}$ - input flow vector (odd directions)

M

atrix elements represent maneuver probabilities and are calculated as:

$$P^{j}{}_{2i-1} = \frac{\lambda^{j}{}_{2i-1}}{\lambda_{2i-1}} \tag{3}$$

where : $\lambda^{j}{}_{2i-1}$ – is the flow intensity toward direction;

λ_{2i-1} – is the total inbound intensity.

Constraint:, (4)

$$\sum_{j=0}^{i} P^{j}{}_{2i-1} = 1 \tag{4}$$

where ^{i} = number of directions.

The matrix structure is:

$$A = \begin{vmatrix} P^{0}{}_{1} & P^{3}{}_{3} & P^{2}{}_{5} & P^{1}{}_{7} \\ P^{1}{}_{1} & P^{0}{}_{3} & P^{3}{}_{5} & P^{2}{}_{7} \\ P^{2}{}_{1} & P^{1}{}_{3} & P^{0}{}_{5} & P^{3}{}_{7} \\ P^{3}{}_{1} & P^{2}{}_{3} & P^{1}{}_{5} & P^{0}{}_{7} \end{vmatrix} \tag{5}$$

Output flows are calculated using:

$$\left.\begin{aligned}\lambda_2 &= P^0{}_1\lambda_1 + P^3{}_3\lambda_3 + P^2{}_5\lambda_5 + P^1{}_7\lambda_7\\ \lambda_4 &= P^1{}_1\lambda_1 + P^0{}_3\lambda_3 + P^3{}_5\lambda_5 + P^2{}_7\lambda_7\\ \lambda_6 &= P^2{}_1\lambda_1 + P^1{}_3\lambda_3 + P^0{}_5\lambda_5 + P^3{}_7\lambda_7\\ \lambda_8 &= P^3{}_1\lambda_1 + P^2{}_3\lambda_3 + P^1{}_5\lambda_5 + P^0{}_7\lambda_7\end{aligned}\right\} \quad (6)$$

After adjusting matrix values with factor coefficients, weekday intensity is calculated:

$$P^j_{2i-1} = W^j_{2i-1} \cdot S^j_{2i-1} \cdot P^j_{2i-1\text{cp}} \quad (7)$$

where: $W^j{}_{2i-1}$ - weekly factors;

$P^j{}_{2i-1}$cp - average maneuver probabilities.

Coefficient values were taken from literature.

The result is traffic intensity diagrams for different days of the week (Figure 2).

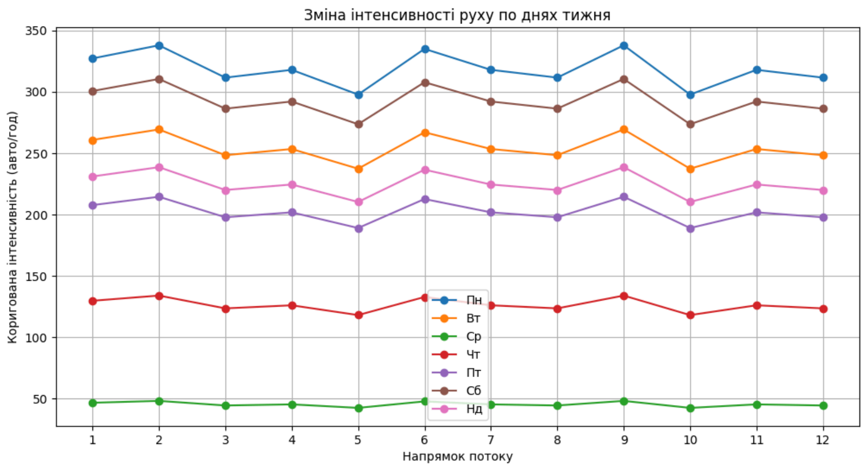


Figure 2 – Weekly traffic intensity variation diagram.

A full matrix of transition probabilities defines what portion of flow turns in each direction. N1–N12 values with corresponding probabilities for each movement direction Example matrix:

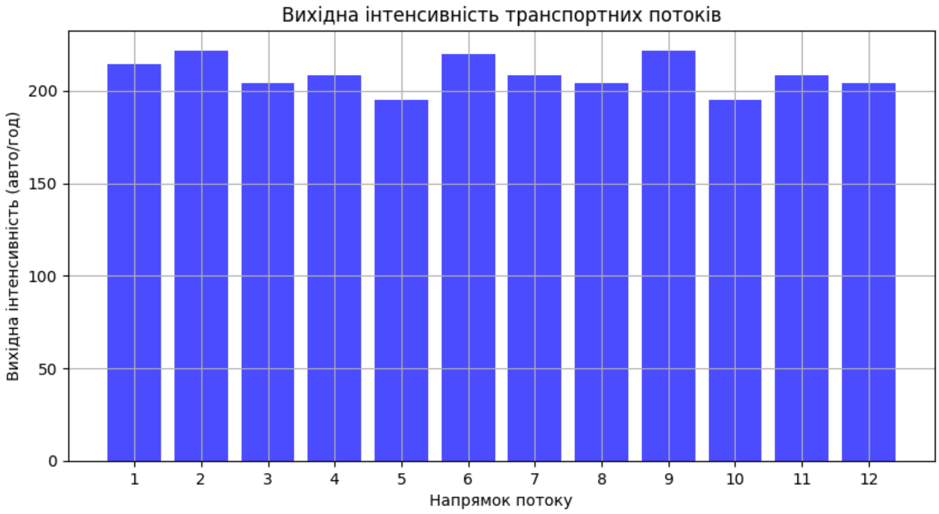
	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
N1	0.1	0.1	0.1	0.05	0.05	0.1	0.05	0.1	0.1	0.1	0.05	0.1
N2	0.1	0.1	0.05	0.1	0.1	0.05	0.1	0.1	0.1	0.05	0.1	0.05
N3	0.05	0.1	0.1	0.1	0.05	0.1	0.05	0.1	0.1	0.1	0.1	0.05
N4	0.1	0.05	0.1	0.1	0.1	0.1	0.05	0.05	0.1	0.1	0.05	0.1
N5	0.05	0.1	0.1	0.1	0.05	0.1	0.05	0.05	0.1	0.1	0.05	0.1
N6	0.1	0.1	0.05	0.1	0.1	0.05	0.1	0.05	0.1	0.05	0.1	0.1

A Python-based program was developed to automate calculations using NumPy and Matplotlib.

Main functions:

- Compute output flows per direction;
- Adjust outputs using weekday coefficients;
- Visualize results with histograms/graphs.

Results showed peak traffic on Monday and Tuesday, with lower levels on Wednesday and Sunday (Figure 3).



The implementation of adaptive control improves traffic efficiency, reduces intersection wait times, and lowers pollution through more rational use of infrastructure. Adaptive systems reduce congestion by 20–30%.

Fixed-cycle signal control considers average flow values. Adaptive systems adjust light phases based on real-time conditions.

This research found that adaptive signal systems reduce average intersection wait time by 30% and increase network capacity.

Real-world implementation will improve traffic control efficiency, reduce congestion, and increase road safety. Modern algorithms and tools are key to building future adaptive transport systems [3].

Future work focuses on signal cycle generation algorithms for program-adaptive control. These systems switch control modes based on time of day and day of week, enabling near-optimal performance under steady traffic conditions and moderate congestion (below 70%).

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DEVELOPMENT OF THE METRO

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Today, the metro is an integral part of many people's lives. But no one thinks about the history of this strange and fascinating mechanism. How did we get to the level we have now? The metro in different cities and countries are as diverse as the people who use them (or the cities in which the metro is located). They can look completely different: from Victorian tunnels, carved by hand, to the most modern underground structures with a fully automated system.

First appearing in the second half of the 19th century, the metro has become an integral part of modern life. Its emergence and development had a significant impact on the economy, urbanization and mobility of the population.

The year of birth of the metro is considered to be 1863, and the birthplace is London. For 27 years, the subway there operated on steam traction and since 1890 –