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# ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

# CAUSES OF TRAFFIC CONGESTION IN CITIES AND THEIR ELIMINATION

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## GENERAL CHARACTERİSTİCS OF THE WORK

**Relevance of the study and Degree of Development.** The rapid growth of motorization has led to issues such as people being stuck in "traffic congestion", time losses, disruption of the ecological balance, the emergence of nervousness and stress, an increase in road traffic accidents, and other related problems.

In recent years, many researchers have studied the causes of "traffic congestion" in several cities. Positive results have been achieved in major cities like Seoul (Republic of Korea), Beijing (People's Republic of China), New Delhi (India), Istanbul (Republic of Turkey), and other large cities in various countries in efforts to eliminate traffic congestion.

In the Republic of Azerbaijan, in 2023, the share of road transport in passenger transportation in the transport sector was 88.1%, while the share of other modes of transport was metro 11.4%, railway 0.37%, air 0.15%, and sea 0.001%. The share of road transport in passenger turnover was 75.8%, while the shares of other modes of transport were air 15.6%, metro 7.7%, railway 0.93%, and sea 0.03%. In the Republic of Azerbaijan, in 2023, the share of road transport in freight transportation in the transport sector was 58.4%, while the share of other modes of transport was pipeline 29.6%, railway 8%, sea 4%, and air 0.2%. Statistical indicators show that road transport has a significant advantage in transportation in the Republic of Azerbaijan.

In addition, several leading countries around the world have built and implemented Intelligent Transport Systems (ITS), simulation programs (such as VISSIM, VISUM, AIMSUN, etc.) for the pre-determination of traffic flows, and smart city and other related projects have been carried out.

One of the key components of Intelligent Transport Systems is the traffic signal control section, where an essential element is the adaptive configuration of the coordinated regulation schedule (the "green wave" system).

Considering these aspects, it can be confirmed that the dissertation work, which focuses on the causes of traffic congestion in cities and their elimination, is relevant in terms of the current demands.

**Research Object and Subject.** The research object of the dissertation is traffic congestion, transportation density in cities, while its subject is preventing these issues and improving transportation conditions. Based on the results of the research, it is emphasized that determining the average speed of vehicles is an important indicator in assessing road density, as well as in the adaptive adjustment of the "green wave" regime.

For this purpose, when investigating the causes of traffic congestion in cities and their elimination, a number of scientific works and articles by various authors have been used and referenced in the course of the research on the current topic.

**Aims and Objectives of the Research.** The goal of the research is to use new approaches in transportation management to establish a coordinated regulation schedule ("green wave" system) in cities and reduce traffic congestion.

In line with the chosen goal, the following issues are to be addressed:

- Investigating the causes of traffic congestions in Baku city;
- Exploring the application of neural network models and artificial intelligence for reliable forecasting of traffic flow parameters;
- Forecasting the average traffic speed on urban streets based on the smart mobility concept;
- Optimizing traffic flows and stimulation of public transportation usage among passengers in the northern entrance-exit direction of Baku;
- Implementing the obtained approaches and results in various streets and roads of Baku;
- Calculating the economic benefits achieved from reducing traffic congestions and environmental pollution in Baku with the proposed approach.

**Research Methods.** To achieve the goal set in the dissertation, data obtained from the Traffic Intelligent Management Center (TIMC) video vehicle detection system (VVDS) and controllers, as well as statistical processing of the data, application of neural networks, and simulation methods were used.

Based on the conducted studies, the research was continued in the following areas:

- Application of innovative approaches;
- Construction of a neural network;
- Expansion of public transportation;
- Improvement of road infrastructure.

**Key Points of the Dissertation.** Among the key points of the dissertation, the following should be emphasized:

- The investigation of the vehicle movement speed as a complex indicator of traffic flow;

- The development of training, evaluation, and testing datasets for predicting the average vehicle speed;

- The implementation of smart projects aimed at improving the efficiency and safety of traffic organization;

- The use of artificial intelligence to predict traffic indicators;

- The proposal of a "green wave" project for Matbuat Avenue in Baku using a neural network;

- The evaluation of the results of neural network training.

**Scientific Innovation of the Research.**

- A method has been developed to ensure the safety of pedestrian and vehicle movement around service facilities, where there is a high density of pedestrians and vehicles, in order to reduce traffic congestion at the city entrances and exits.

- Neural networks have been used for the adaptive organization of the "Green Wave" system.

- Data on average traffic speeds at real city street intersections and from surveillance cameras were analyzed to create test corpora for the model developed using the neural network.

- The technical regulation of traffic control systems and all factors that could influence traffic organization, such as traffic intensity and speeds, were studied for the streets and avenues in question. Based on this analysis, the average traffic speed, used as an input parameter, was predicted with 95% accuracy.

**Theoretical and Practical Significance of the Research.** The main results obtained have significant theoretical and practical importance. The development of road transportation in the modern era impacts various aspects of the economy, culture, and social life. This development has both positive and negative aspects, with its pace now encompassing not only economic but also social issues. Furthermore, in the practical phase, road transport development raises issues such as traffic congestion, time losses, environmental problems, increased nervousness and stress, and a rise in transportation accidents. The theoretical foundation of the dissertation is based on numerous studies, scientific research, references to works by both local and foreign authors, as well as participation in various conferences related to the topic.

**Approval and Implementation.** The main points of the dissertation were presented and discussed at various scientific conferences, including the Republican Scientific Conference on "Globalization and Regional Integration" organized by the Ministry of Education of the Republic of Azerbaijan at Mingachevir State University (Mingachevir, 2016), the XX Republican Scientific Conference for Doctoral Students and Young Researchers organized by the Ministry of Education of the Republic of Azerbaijan (Baku, 2016), the Republican Scientific-Technical Conference on "Youth and Scientific Innovations" dedicated to the 94th anniversary of the birth of the National Leader of the Azerbaijani people, Heydar Aliyev, organized by the Ministry of Education of the Republic of Azerbaijan at Azerbaijan Technical University (Baku, 2017), the International Scientific-Practical Conference on "Azerbaijan in the International Transport System: Goals and Perspectives" at Baku Engineering University (Baku, 2018), the Republican Scientific Conference on "Transport of Azerbaijan: Achievements, Problems, and Perspectives" (Baku, 2019), and the II International Scientific-Practical Conference on "Progressive Research in the Modern World" (Boston, 2002).

Two scientific articles related to the dissertation work were also published in the “Scientific Works Journal” of the Ministry of Education of the Republic of Azerbaijan, Azerbaijan University of Architecture and Construction, in the journal "Automobile transport. Collection of scientific works" in the Republic of Ukraine, and in the "Journal of traffic and transportation research" in Turkey.

To further explore the issues addressed in the dissertation, the author has participated in various local and international training programs. These include the "Intellectual Technologies in Machine Engineering" International Scientific-Technical Conference held at AzTU in 2016, the "Azerbaijan in the International Transport System: Goals and Perspectives" International Scientific-Practical Conference at Baku Engineering University in 2018, the "International Road Safety Engineering" Seminar in Baku in 2019, the "Infrastructure Planning and Development" Seminar organized by the Ministry of Finance in Beijing, China, in 2019, the "Bus Transport Systems Planning" training program in India in 2020, the "EBRD – Road Safety Engineering" Webinar in 2021, the "Development of Road Safety Engineering" Seminar for CAREC countries (Kazakhstan) in 2021, the Asia-Pacific Safe Road Infrastructure Webinar in 2022, the "Development of Road Safety Engineering" Seminar for CAREC countries (Turkmenistan) in 2022, the International Regional Road Safety Research Dialogue and the Asia-Pacific Road Safety Research Annual Meeting in the Philippines in 2022, and the II International Scientific-Practical Conference on "Progressive Research in the Modern World" in Boston in 2022. In 2023, the author participated in the "Evaluation of Arterial Signal Coordination Performance Using Automated Vehicle Trajectories" training in Florida and obtained certificates for these programs.

Furthermore, a patent for the "Method of Ensuring the Safety of Pedestrian and Vehicle Movement in the Bus Station Area" was granted by the Intellectual Property Agency of the Republic of Azerbaijan under the patent number I2020 0041.

The main provisions of the dissertation have been implemented in the ITMC, the authorized institution responsible for traffic light management in Baku. A report has been prepared regarding the proposed method for eliminating traffic congestion, which includes the possibility of adaptively changing the “green wave” mode at any time of the day. It is believed that its implementation will help reduce delays in traffic flows.

Additionally, considering the practical significance of the provisions related to the “green wave” mode, the Ministry of Internal

Affairs of the Republic of Azerbaijan, through the Main State Traffic Police Department's “Signal” Specialized Project Production Department, has accepted the implementation of these provisions in the traffic lights managed by this department. Based on the dissertation's provisions, a report was prepared for the specialists responsible for the installation and management of traffic light systems, with recommendations for determining the speed limit.

**Name of the organization where the dissertation was carried out.** The dissertation was carried out at the "Transport Logistics and Traffic Safety" Department of Azerbaijan Technical University, under the Ministry of Science and Education of the Republic of Azerbaijan.

**Structure and total volume of the dissertation, with individual sections specified.** The dissertation consists of 184 pages of computer-written text, including an introduction, four sections, and conclusions, as well as a list of 13 pages of references, 17 pages of appendices, and 1 page of abstracts. The length of the introduction is 19,288 characters, the first chapter is 68,904 characters, the second chapter is 68,044 characters, the third chapter is 31,233 characters, and the fourth chapter is 29,158 characters, with the total length being 215,772 characters. The dissertation includes 9 figures, 32 tables, 13 diagrams, 6 charts, 2 graphs, a reference list with 120 entries, and 10 appendices.

## SHORT SUMMARY OF THE DİSSERTATİON

**In the introduction,** the topic of the dissertation is justified, and its relevance, research objectives, and the issues to be addressed are outlined. The ways and methods for solving the problem are identified, and the scientific novelty of the research is presented. The impact of the current development of road transport on various aspects of the economy, culture, and social life is investigated. The practical significance of the research results for the application in the Azerbaijani transport system is also highlighted.

**The first chapter** covers topics such as the causes of traffic jams, methods for eliminating traffic congestion, the investigation of the speed of road vehicles as a complex indicator of traffic flow, analysis of statistical data on traffic jams in Baku, the goals of the research, and directions for solving the problem.

Several studies dedicated to investigating the causes of traffic congestion in cities clearly observe that traffic congestion remains a problem in many developed and developing countries and poses a threat to the quality of urban life. Regardless of whether traffic congestion is significant or not, it can arise due to various causes, many of which are outlined below:

- An excessive number of vehicles in the traffic flow due to inadequate public transportation or other reasons;
- Obstacles on the road causing congestion and bottlenecks;
- Double-sided parking along the roadside;
- Ongoing construction work on the road;
- Closure of traffic lanes due to communication work;
- Road narrowing;
- Road traffic accidents;
- Lack of synchronization between traffic lights and the devices controlling them;
- The signal duration of traffic lights not being calculated according to real time;
- Overcrowded areas caused by a dense public transport network and an insufficient street-road network, and so on.

It is known that when traffic lights are ideally coordinated and respond to demand in real-time, the road's capacity for traffic flow can be increased. To eliminate the causes of traffic congestion, automatic data collection tools for road conditions, flexible mathematical models of traffic flows, and software developed based on them should be used. Determining the average speed of vehicles is crucial for assessing road congestion. In Baku city, accurate and detailed information about the average speed of vehicles is collected through video detection cameras.

When investigating the causes of traffic congestion, it has been determined that traffic vehicles face congestion even during non-peak hours as a result of the disruption of the "green wave" system. The main reasons for the disruption of the "green wave" are the improper determination of the recommended speed on streets and avenues where the traffic light schedule is set, the presence of unregulated pedestrian crossings, and the different phases at regulated intersections on the studied streets and avenues .

As seen from the above, the traffic congestion problem exists in most cities around the world. The question of why the causes of this problem, existing both globally and in Azerbaijan, still persist and what actions are needed to prevent it is an important topic of study. The research work carried out here is dedicated to addressing this issue based on all the aforementioned causes.

**In the second chapter,** it covers proposals for eliminating the causes of traffic congestion, the study of technical regulation tools used in traffic management, the investigation of the movement intensities of vehicles, the determination of the average movement speeds of vehicles in Baku, the prediction of traffic indicators using artificial intelligence, and the establishment of a neural network for predicting the average movement speed of vehicles.

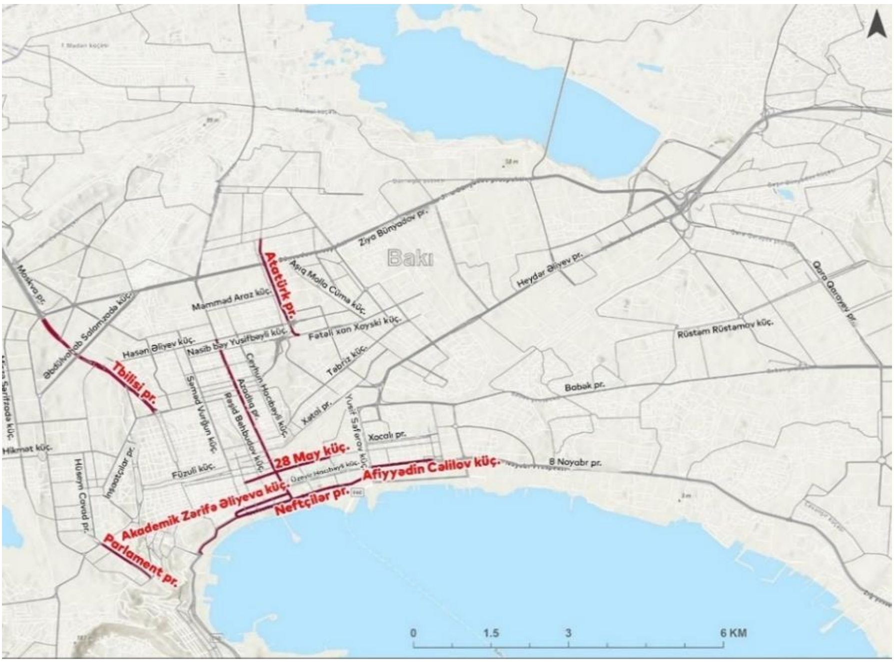


**Figure 1. Streets and Avenues Studied in the Research**

To solve the main idea of the research, 8 streets and avenues in Baku city were examined (see Figure 1). Data on vehicle intensity and average movement speed were collected over a period of 15 working days, 24 hours a day, at 22 points on these streets and avenues.

Additionally, the following information was studied and analyzed for the streets and avenues examined, from the beginning of the street and avenue to the VVDS point and from the VVDS to the end of the road:

- The total length of the road;
- Movement directions (the direction of movement may change on certain parts of the road);
- The number of traffic lanes;
- The number of controlled and uncontrolled intersections;
- The number of pedestrian lanes and various types of pedestrian overpasses;
- The number of bus routes and "pocket" type bus stops;
- The number of bus and taxi stops;
- The number of vehicle parking areas (parking spaces);
- The number of lanes occupied by parking;
- The number of points of interest, electronic boards, U-turns, and road signs;
- The variation in the optimal cycle length of traffic regulation at controlled intersections, based on weekly, daily, and hourly changes.

In addition to the main idea of the research, several projects aimed at improving the efficiency and safety of traffic management in Baku city are presented in the structure shown in Figure 2.

As it is known, the change in movement speed is one of the main causes of traffic congestion, which indicates that improper speed regulation affects the disruption of the "green wave" system.

During the studies conducted on the use of neural networks for forecasting the speed of motor vehicles, it was determined that neural networks have been widely used in various fields to solve arising problems.

In the establishment of the "green wave" graph, to determine the recommended traffic speed, the average movement speeds were forecasted using the construction of a neural network, and a fully connected closed neural network model was used for this purpose.

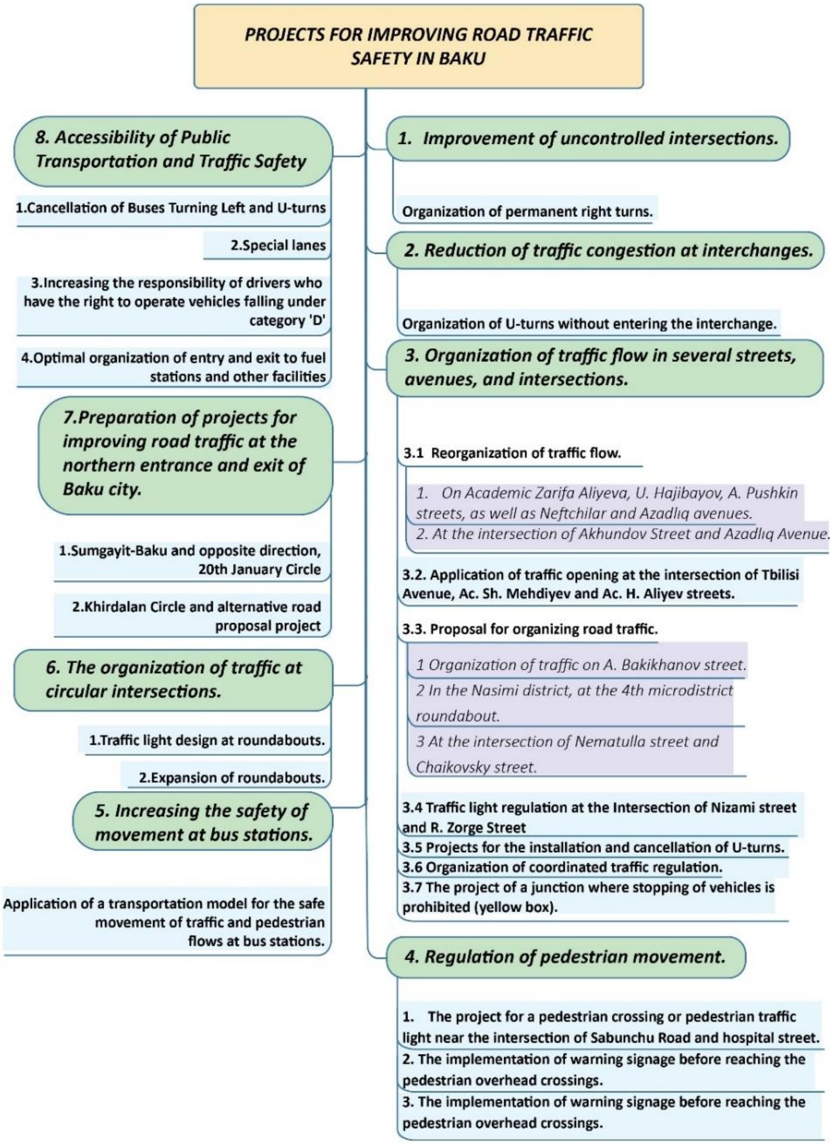


**Figure 2. Structural overview of projects for improving road traffic safety in Baku city**

As shown in the diagram in Figure 3, in the multilayer perceptron, all parameters affecting congestion, such as distances before and after the observed point, VVDS, the number of infrastructure objects for motor transport, the number of technical regulation tools for traffic management, the duration of optimal adjustment times, the number of phases, the number of road signs, as well as information about traffic intensities and average movement speeds in the streets and boulevards under consideration, are entered layer by layer. Then, hidden layers resulting from mutual influence are determined, followed by the output layer.

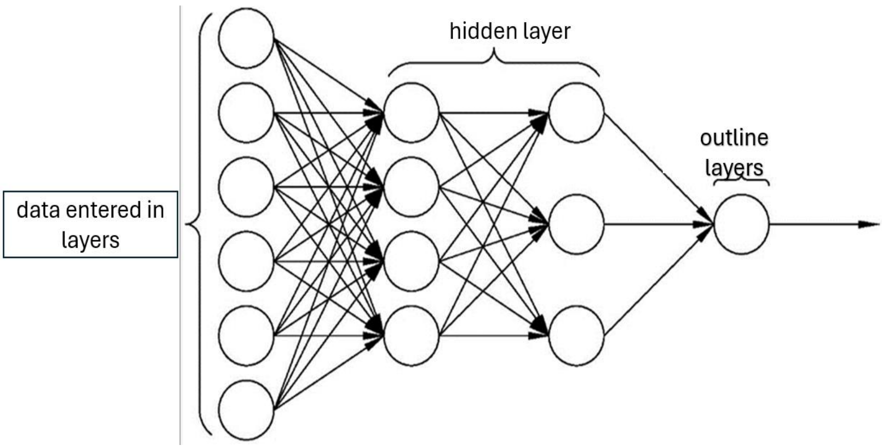


**Figure 3. Multi-layer Perceptron with an Input Layer, 2 Hidden Layers (with 4 and 3 neurons in each layer, respectively), and an Output Layer with a Single Output Neuron.**

Additionally, potential procedures for both data processing and optimization that can be generalized to other machine learning methods controlled by a lightweight neural network with network traffic classification in real-time can be explored. A fast method for identifying the key attributes in a neural network based on connection weights can also be noted.

Furthermore, when using the attributes determined by the weights of the neural network, it has been found that these attributes have higher performance compared to those defined by the symmetric uncertainty rating in these studies.

Thus, in the dissertation, the causes of traffic congestion and their elimination were investigated, with a focus on predicting the average movement speed in traffic using artificial intelligence, as well as the establishment of a neural network, and satisfactory results were obtained.

**In the third chapter,** topics such as the creation of test corpora for predicting the average movement speed of vehicles, training the neural network, and evaluating the results of neural network training are discussed.

Since a neural network is a collection of individual neurons connected by a specific structure, the computational power of the network, i.e., the tasks it can perform, is determined by these connections.

In this regard, considering that artificial intelligence methods are currently used in various technical fields, economics, finance, and other areas for prediction and classification tasks, the dissertation explores the prediction of the average movement speed in traffic using artificial intelligence to address the causes of traffic congestion and their elimination. Satisfactory results with a 4.52% error rate were obtained for previously unseen observations during training.

While preparing the dissertation, the neural network application program was written in Python 3.5 programming language. The Microsoft CNTK module was also used for training neural networks, and the file cntk_dnn.py was written in Python 3.5 for training the neural model. The file cntk_dnn_evaluation.py was written in Python 3.5 for evaluating the trained model in the test corpus.

In line with predicting the average movement speed of vehicles in cities, observations, surveys, and analyses were conducted on several streets and avenues of Baku city to evaluate the trained model's test corpus.

For the construction of the test corpora of the trained model, data on the average movement speeds of vehicles were analyzed from video detection cameras installed at 22 different locations on 8 different roads in the capital for 15 working days, 24 hours each day.

Data was collected from VVDS installed on the following streets and avenues in Baku city:

1. 4 points on 28 May Street;
2. 2 points on Azadliq Avenue (from the intersection with Academician Hasan Aliyev Street to Neftchilar Avenue);
3. 3 points on Neftchilar Avenue;
4. 2 points on Parliament Avenue;
5. 6 points on Tbilisi Avenue;
6. 2 points on Academician Zarifa Aliyeva Street;
7. 1 point on Afiaddin Jalilov Street;
8. 2 points on M.K. Ataturk Avenue.

The total number of observations for the 22 points, collected over 15 working days and 24 hours each day, amounted to 7920 cases, as shown by the product below:

$$22 \times 15 \times 24 = 7920 \text{ cases.}$$

Additionally, data from 18 points across 6 streets and avenues of the mentioned roadways were used for training, while data from 2 points on 1 street (Academician Zarifa Aliyeva Street) were used for evaluation, and data from 2 points on 1 street (Parliament Avenue) were allocated for testing. During the reporting process, the observation cases were divided as shown in Table 1.

**Table 1.**
**Division of Observation Cases**

| Training | Evaluation | test | total |
|---|---|---|---|
| 7200 | 360 | 360 | 7920 |

In total, 53 road characteristics were considered in the issue of predicting the average movement speed of vehicles in cities, using the example of Baku city.

Additionally, when considering the time indicators expressed in full hours and the movement speeds of vehicles recorded by the GPS system, a matrix of size 7920 x 55 was obtained.

During the study of international practices, it was determined that algorithms based on neural networks are widely used in transportation-related problems due to their high flexibility, good learning, and generalization capabilities. Furthermore, the recurrent neural network, with its special internal structure that can effectively process data from subsequent days, has been applied in traffic flow forecasting.

When considering a neural network consisting of various neurons, the process shown in Figure 4 will be designed:

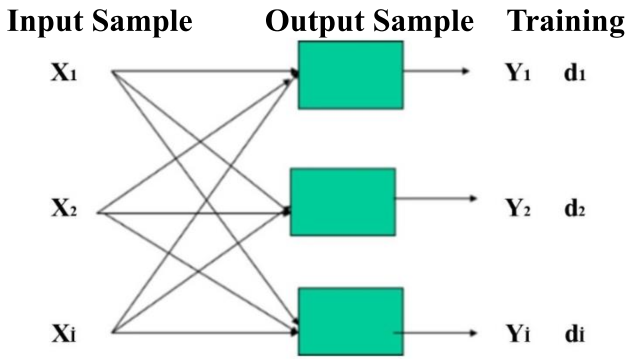


**Figure 4. The learning process of the neural network.**

In Figure 4 the vectors $\{X_1, X_2, X_i\}$ and $\{d_1, d_2, d_i\}$ represent the training pairs, and all the parameters affecting traffic congestion, such as the distances before and after the observation points on the examined streets and avenues, VVDSs, infrastructure objects for road transport, the number of technical regulation tools for traffic management, the optimal regulation times for traffic lights, the number of phases, the number of road signs, as well as the traffic intensity and average traffic speeds on the examined streets and avenues, are entered as layers. Then, the hidden layers created from the interactions between them are processed, and finally, the results of the training, i.e., the average traffic speeds, are determined in the output layers[1].

[1] Thorsell, E. Vehicle speed-profile prediction without spatial information: / master thesis /– Gothenburg, 2018. – 81 p

In the dissertation, 53 road characteristics and time (in full hours) are used for training (a total of 54 indicators), normalized based on the mean and variation, and entered into the neural network input. For a given vector $X = (x_1, x_2, ..., x_{54})$, the neural network outputs the forecasted Y traffic speed for the corresponding hour, $Y = f(X)$.

The neural network learns the parameters that minimize this error over the training set[2]. The training corpus consists of 7200 observations. All the weight coefficients of the neural network are initialized with a uniform distribution in the range (-0.02, 0.02). The learning coefficient for continuous accumulation is taken as constant, as follows:

$$\alpha = 0.05$$

Based on research and calculations, for the purpose of predicting the traffic flow, one of the test corpora allocated to evaluate the results of the training was used with 2 detector cameras on a road. During the training, different values for the number and size of the layers were examined, and it was determined that the best results were obtained when the number of layers was n = 5 and the size was 20.

Accordingly, the number of learned parameters was determined as follows:

$$54 \times 20+20 \times 20 \times 4+20 \times 6 + 1 = 2801$$

The model provides a forecast for the average traffic speed for each hour of the day[3]. In order to compare with the real indicators, the values for each hour of the 15 workdays have been determined. Statistically, the average values for each hour over the 15 workdays

[2] Fajariyanto, E., Fajar.M. Performance of Logistic Regression and Multilayer Perceptron Neural Network in Classification of Objects // – İndia: International Journal of Scientific Research in Mathematical and Statistical Sciences,– 2021. №1, – p. 52-55.

[3] Ciptaningtyas, H.T., Fatichah, C., Sabila, A. Network traffic anomaly prediction using Artificial Neural Network // AIP Conference, USA, – 2017. – p.16.

should be calculated using the average values from the equation 1 below.

$$y_i = \frac{1}{15}\sum_{i=1}^{15} y_{i,f} \qquad i = 1, \dots ,24 \tag{1}$$

here

$y_{i,f}$ represents the average movement speed of vehicles recorded by the detector camera on the i-th hour of the j-th day.

To evaluate the quality of the prediction, the mean absolute error was used. For this purpose, the average relative difference between the forecasted values and the actual values for each hour over 24 hours was taken, as shown in equation 2 below[4]:

$$\overline{y_i} = \frac{1}{24}\sum_{\mathrm{i}=1}^{24} \frac{|\widehat{y_i} - y_i|}{y_i} \times 100\% \tag{2}$$

**Table 2.**

**The forecast of average movement speeds of vehicles based on the model.**

| time | 1st detector camera | | 2nd detector camera | |
|---|---|---|---|---|
| | Average movement speed based on observations | Forecast of the average movement speed based on the model | Average movement speed based on observations. | Forecast of the average movement speed based on the model. |
| 04:00 | 58.2 | 52.94 | 53.07 | 54.23 |
| 08:00 | **45.00** | **45.28** | 51.67 | 54.02 |
| 12:00 | **43.67** | **43.54** | **52.47** | **53.11** |
| 16:00 | 45.60 | 43.64 | 52.33 | 51.30 |
| 20:00 | **47.87** | **48.20** | **51.47** | **50.85** |
| 24:00 | 54.40 | 52.88 | 55.40 | 53.42 |

[4] Belhadi, A. A recurrent neural network for urban long-term traffic flow forecasting / A.Belhadi, Y.Djenour, D.Djenouri [et al.] // Springer, – Berlin: – 2020. №50, – p. 3252-3265

The models were compared using this error criterion, and it was determined that the model with the best results had a mean absolute error of 4.52%.

Accordingly, in Table 2, forecasts based on the average traffic speeds of vehicles observed by VVDSs at certain hours in the test corpus are provided. As shown in the table, in certain cases, predictions were made that are very close to the real results (with a difference of less than 1 km/h).

In the dissertation, the results of training were evaluated by using detector camera observations for forecasting traffic flow, based on the average vehicle movement speed data over a certain period. The elimination of traffic congestion, as well as the experimental study of traffic flows, was analyzed, and the results of the neural network training were reviewed.

**In the fourth chapter,** topics such as the construction of confidence intervals for the average vehicle movement speeds, forecasting traffic indicators using artificial intelligence, the creation of the 'green wave' graphic on Matbuat Avenue and Academician Zarifa Aliyeva Street in Baku, as well as the justification of the expected economic benefits from the implementation of the 'green wave' system, are discussed.

As mentioned in the dissertation, even during peak hours, traffic congestion is caused by the disruption of the 'green wave' system. For this purpose, by using artificial intelligence, a programmed confidence interval for the speed limit was created with 95% accuracy, as shown in Chapters II and III, and was learned with high precision. The research, methodology, and solutions presented in the dissertation were conducted on 8 streets in Baku city. Specifically, data from 6 streets were analyzed, while data from 2 other streets were verified, and the 'green wave' graphic was designed for Matbuat Avenue and Academician Zarifa Aliyeva Street, with the 'green wave' applied on Matbuat Avenue. Since rigid programming was used in previous cases, the current model will enable the 'green wave' graphic to be executed in an adaptive form. After the relevant analyses, a diagram showing the dependency of the average vehicle movement speeds on the hours of the day, separately for each day of the month, was created (Figure 5).

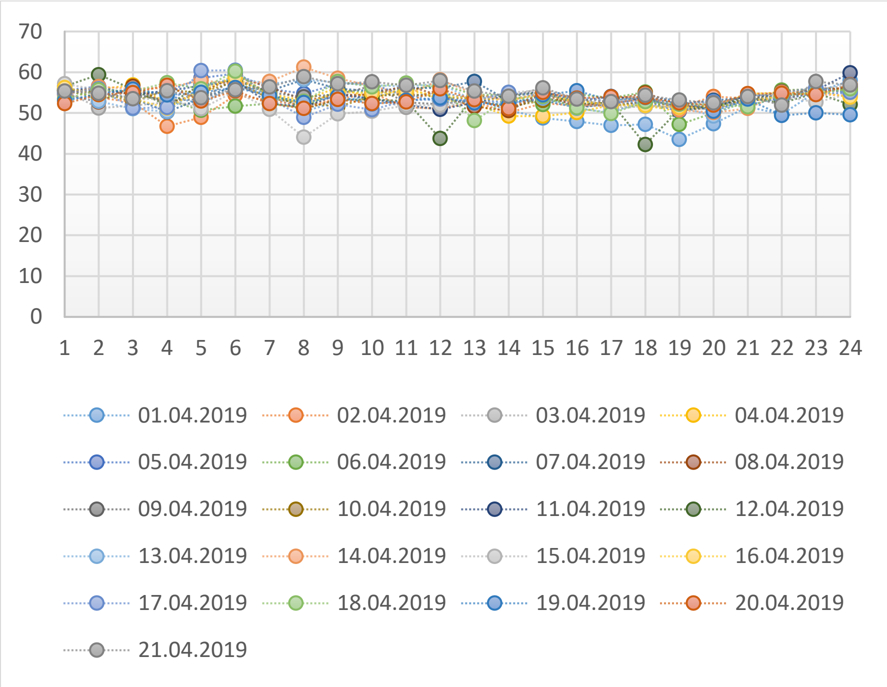


**Figure 5. Comparative diagram of the average movement speed indicators of vehicles for April 21st, showing the hourly distribution throughout the day.**

Subsequently, based on the data collected from the area and the research, the following values were determined for the first three weeks of April, considering only weekdays and the hours of the day: the unbiased statistical estimate for the mathematical expectation, the unbiased statistical estimate for the standard deviation, the quantile for the Student's distribution, the lower boundary, the upper boundary, and the difference between them. Additionally, the degrees of freedom (df) and the confidence level indicator were calculated (Table 3).

**Table 3.**
**The values of the indicators of degrees of freedom and reliability**

| Time | $v_{RG}$ | $Y_{SY}$ | df | Degree of reliability | $v_{as}$ | $v_{ys}$ | Difference |
|---|---|---|---|---|---|---|---|
| 01:00 | 55.14 | 1.18 | 14 | 95.00% | 54.49 | 55.79 | 1.31 |
| 02:00 | 55.14 | 1.85 | | | 54.12 | 56.16 | 2.04 |
| 03:00 | 54.38 | 1.76 | | | 53.40 | 55.35 | 1.95 |
| 04:00 | 53.15 | 2.52 | | | 51.76 | 54.54 | 2.79 |
| 05:00 | 54.79 | 2.95 | | | 53.15 | 56.42 | 3.27 |
| 06:00 | 57.98 | 1.77 | | | 57.00 | 58.96 | 1.96 |
| 07:00 | 54.11 | 1.35 | | | 53.36 | 54.86 | 1.50 |
| 08:00 | 51.67 | 2.53 | | | 50.27 | 53.07 | 2.80 |
| 09:00 | 54.13 | 2.10 | | | 52.97 | 55.29 | 2.32 |
| 10:00 | 54.00 | 1.93 | | | 52.93 | 55.07 | 2.13 |
| 11:00 | 53.85 | 1.95 | | | 52.77 | 54.92 | 2.16 |
| 12:00 | 52.53 | 2.90 | | | 50.92 | 54.13 | 3.21 |
| 13:00 | 52.69 | 1.39 | | | 51.92 | 53.47 | 1.54 |
| 14:00 | 52.44 | 1.85 | | | 51.42 | 53.47 | 2.05 |
| 15:00 | 53.59 | 2.05 | | | 52.45 | 54.73 | 2.27 |
| 16:00 | 52.33 | 1.80 | | | 51.33 | 53.33 | 2.00 |
| 17:00 | 51.80 | 1.66 | | | 50.88 | 52.72 | 1.84 |
| 18:00 | 51.81 | 3.16 | | | 50.06 | 53.56 | 3.50 |
| 19:00 | 50.97 | 2.17 | | | 49.77 | 52.17 | 2.41 |
| 20:00 | 51.45 | 1.44 | | | 50.66 | 52.24 | 1.59 |
| 21:00 | 53.19 | 0.97 | | | 52.66 | 53.73 | 1.07 |
| 22:00 | 53.59 | 1.80 | | | 52.60 | 54.59 | 1.99 |
| 23:00 | 54.79 | 1.54 | | | 53.94 | 55.65 | 1.71 |

The calculations for each day of the first three weeks of April 2019 were carried out according to the following sequence 3 for 01:00

AM [5]:

- The bias-free statistical estimate for mathematical expectation is calculated as shown in the 3rd equation:

$$v_{RG} = \frac{\sum_{i=1}^{21}(v_{orI}+v_{orII}+v_{orIII})}{15} = 55.14\ km/hour \quad (3)$$

here

$v_{orI}, v_{orII}, v_{orIII}$– accordingly, the total of the average movement speed indicators of the vehicles for the 1st, 2nd, and 3rd weeks of April was calculated.

15 refers to the number of days the calculation was performed.

- The bias-free statistical estimate for standard deviation is calculated as follows, according to the formula stated in the 4th equation:

$$Y_{SY} = \sqrt{\frac{\begin{array}{c}(v_{orI1}-v_{RG})^2+(v_{orI2}-v_{RG})^2+(v_{orI3}-v_{RG})^2+(v_{orI4}-v_{RG})^2+\\(v_{orI5}-v_{RG})^2+(v_{orII1}-v_{RG})^2+(v_{orII2}-v_{RG})^2+(v_{orII3}-v_{RG})^2+\\(v_{orII4}-v_{RG})^2+(v_{orII5}-v_{RG})^2+(v_{orIII1}-v_{RG})^2+\\(v_{orIII2}-v_{RG})^2+(v_{orIII3}-v_{RG})^2+(v_{orIII4}-v_{RG})^2+(v_{orIII5}-v_{RG})^2\end{array}}{14}}, \quad (4)$$

here

$v_{orII}, v_{or12}, v_{or13}, v_{or14}$ , $v_{or15}, v_{orII1}, v_{orII2}, v_{orII3}, v_{orII4}, v_{orII5}, v_{orIII1}, v_{orIII2}, v_{orIII3}, v_{orIII4}, v_{orIII5}$-accordingly, the average movement speed of vehicles for the 1st to 5th days of the 1st, 2nd, and 3rd weeks of April was calculated.

14 refers to the number of days the calculation was performed.

- The calculation of the upper bound value for speed is based on the following formula, as stated in the 5th equation:

$$v_{ys} = v_{Rg} - \frac{2.14 \times Y_{SY}}{\sqrt{15}}, \quad (5)$$

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[5] Kart, O., Chaghri, G.O., Bashchiftchi, F. Speed Compatible Green Wave Corridor with The Internet of Things // – İstanbul : European Journal of Science and Technology, – 2021. № Special 28, – p. 411-416.

here

2.14 - The quantile for the Student distribution;

- The lower bound value is determined based on the calculation shown in the 6th equation:

$$v_{as} = v_{Rg} - \frac{2.14 \times Y_{SY}}{\sqrt{15}}, \quad (6)$$

here

$v_{as}$ - the lower bound value of speed.

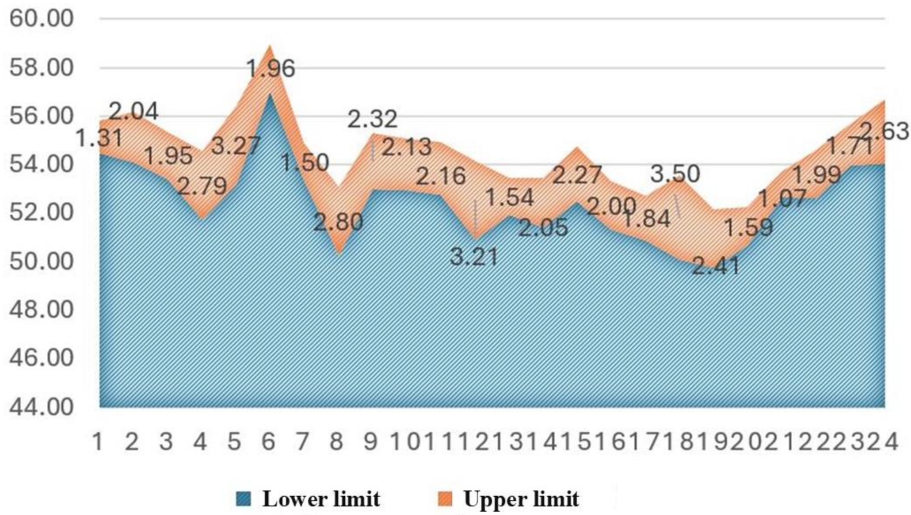


**Figure 6. Comparative Diagram of the Difference Between the Upper and Lower limits of the Average Movement Speed Indicators of Vehicles by Hours on April 21.**

As a result of the calculations, the comparative situation arising from the difference between the upper and lower bounds of the average vehicle movement speed indicators during the hours of the day on April 21st is shown in Figure 6[6].

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[6] Kiers, M., Visser, C. The Effect of a green wave on traffic emissions // Proceeding of: International E[55nergie wirts chaftstagung Conference Viene Technological University, – Viene: Sciences Research, – 2017, p. 7.

As mentioned in the dissertation, with the help of artificial intelligence methods, it is possible to determine the recommended speed in the 'green wave' graphic. This allows for a more realistic determination of the recommended speed, in line with the traffic flow. At the same time, by studying the causes of traffic congestion in cities, research has been conducted in the case of Baku city to propose solutions for their elimination. This aims to investigate existing statistical indicators in the field of road transport and provide suggestions in this direction. Following the above-mentioned information, the results of the report on the construction of a coordinated regulation schedule for the interchanges on Matbuat Avenue in the direction of the 'Green Wave' implementation are given in Table 4.

**Table 4**

**Report on the construction of the coordinated control schedule.**

| Intersections of Matbuat Avenue | $T_{Cy}$ sec | $T_C$ sec | $T_a$ sec | $a$ | $t_g^*$ sec | $t_r^*$ sec | $T_T^*$ sec |
|---|---|---|---|---|---|---|---|
| A.Sultanova str. | 58 | 50 | 91 | 33 | 33 | 50 | 91 |
| M.Rahim str. | 97 | 89 | 91 | -6 | 63 | 20 | 91 |
| B.Vahabzadeh str. | 114 | 106 | 91 | -23 | 66 | 17 | 91 |
| A.Haghverdiyev str. | 79 | 71 | 91 | 12 | 58 | 25 | 91 |
| A.Abbasov str. | 65 | 57 | 91 | 26 | 52 | 31 | 91 |

here

$T_{Cy}$ - optimal cycle lengths of regulation;

$T_C$ - conditional cycle lengths;

$T_a$ - calculated regulation cycle lengths;

a - the difference between the cycle lengths;

$t^*_g$, $t^*_r$ – the duration of green and red light phases at intersections where the work modes are corrected;

$T^*_{Cy}$ - total cycle length.

Furthermore, the dissertation includes the development of several projects aimed at increasing road safety and efficiency in traffic management in Baku city. To achieve this goal several studies were conducted on Matbuat Avenue in Baku, and the 'green wave' graphic was created as shown in Figure 7.

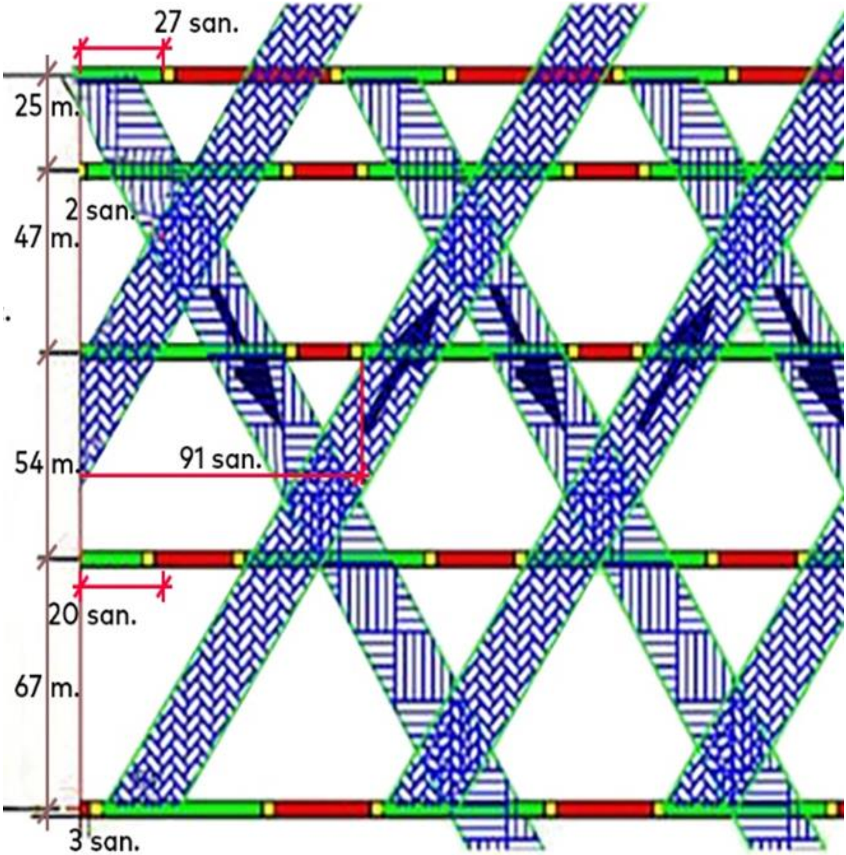


**Figure 7. Coordinated control schedule established on the Matbuat Avenue.**

As a result of the calculations conducted in the direction of establishing the 'green wave' system, the recommended vehicle speed from the intersection of Matbuat Avenue with A. Sultanova Street to the intersection with A. Abbasov street was determined to be 55 km/h, while the recommended speed in the opposite direction was 50 km/h. Additionally, the horizontal scale was taken as 1 cm for 10 seconds, and the vertical scale as 1 cm for 100 meters. It was determined that the width of the time scale was 24 seconds.

The optimal cycle lengths of the traffic regulation at the interchanges on Zarifa Aliyeva Street are shown in Table 5.

**Table 5**
**The main signal cycle lengths at the intersections of Academic Zarifa Aliyeva Street with other streets and avenues**

| Optimal cycle lengths of the signalization cycle | **R.Behbudov street** | **Bulbul Avenue** | **S.Vurghun street** |
|---|---|---|---|
| $T_T$ | 60 | 60 | 60 |

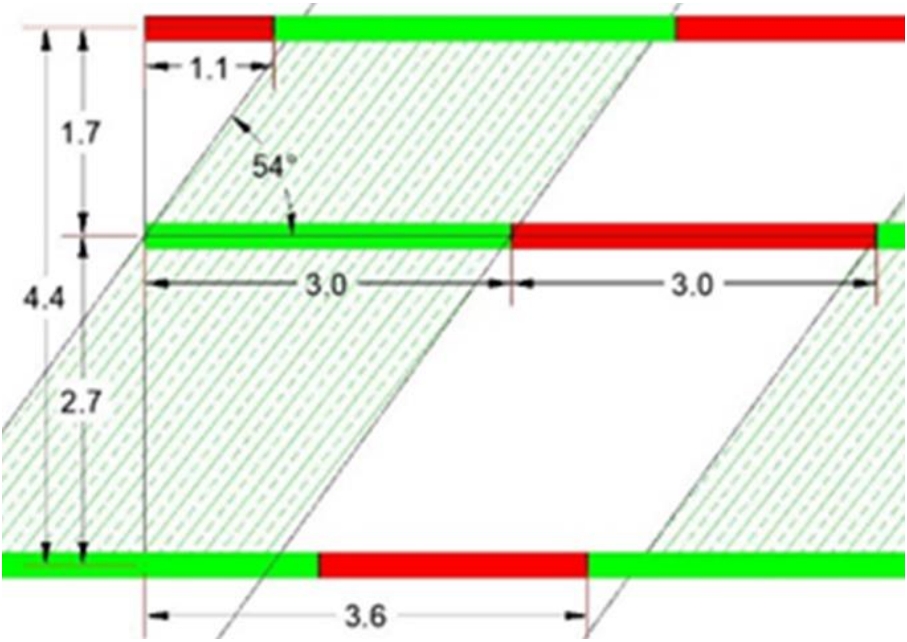


**Figure 8. Coordinated regulation schedule established on Academic Zarifa Aliyeva Street**

Additionally, because of the calculations conducted in the direction of establishing the 'green wave' graphic, the recommended vehicle speed on Academician Zarifa Aliyeva Street was determined to be 50 km/h. As shown in Figure 8, the horizontal scale was set to 1 cm for 10 seconds, and the vertical scale was set to 1 cm for 100 meters, with the width of the time scale being 24 seconds. This project was developed accordingly.

The economic benefit that can be achieved by reducing time losses during the organization of continuous movement on the roads has been analyzed. In the analysis, the average vehicle movement speed indicators were taken for Academician Zarifa Aliyeva Street between 00:00-07:00 hours. The number of observations is 147, covering the period from April 1st to 21st, 2019, and 8 hours of each day.

**Table 6.**

**Economic Analysis Results for Academic Zarifa Aliyeva Street**

| | |
|---|---|
| Mean | 44.19 |
| Standard error | 0.33 |
| Median | 44.04 |
| Standard deviation | 1.50 |
| Sample variance | 2.25 |
| Kurtosis | 0.00 |
| Skewness | -0.14 |
| Range | 5.62 |
| Lower bound of the interval | 41.20 |
| Upper bound of the interval | 46.82 |
| Number of days observed | 21.00 |
| Confidence level (95.0%) | 0.68 |

The upper limit of the interval is calculated as the sum of the product of the arithmetic mean and the t-value for 95% of the standard error. The main purpose of calculating this interval is to express confidence in the accuracy of the data, assist in decision-making, and understand how close the results are to the population through hypothesis testing. Based on the results obtained from the data, the confidence level on Academician Zarifa Aliyeva Street is equal to 0.68. According to this interval, as shown in Table 6, the population mean is likely to fall between 43.51 and 44.87 with 95% confidence.

After analyzing the statistical indicators, we can conclude that, as a result of implementing the 'green wave' system, the average vehicle speed on Academician Zarifa Aliyeva Street will be 50 km/h. This is 6 km/h higher than the current average speed.

According to the calculations based on the mentioned data, the fuel and time savings per 1 km corresponding to the speed limits have been calculated and are provided in Table 7.

**Table 7.**
**Indicators for fuel and time savings per kilometer according to speed limits**

| № | Indicator Fuel Savings | Speed Limit, km/h | | difference | |
|---|---|---|---|---|---|
| | | 44 | 50 | Physical unit of measurement | Value in Terms (in Manat) |
| 1 | Time Savings | 0.064 l | 0.06 l | 0.004 l | 0.0044 |
| 2 | Indicator | 1.36 minute | 1.2 minute | 0.16 minute | 0.0187 |
| Total | | | | 0.0231 manat | |

As shown in Table 8, the expected annual economic benefit from the implementation of the "green wave" project, which involves regulating the traffic flow on the street through traffic light adjustments is 284,156 manat.

The length of Academic Zarifa Aliyeva Street is 0.9 km, and taking into account the number of vehicles passing through the street, the fuel and time savings over the course of one year will be as shown in Table 8.

**Table 8.**
**Fuel and time savings indicators per 1 km according to speed limit**

| № | Source of Savings | Amount of Savings (manat) |
|---|---|---|
| 1 | Fuel Savings | 54125 |
| 2 | Time Savings | 230031 |
| Total | Total Savings | 284156 |

## Results

Key Scientific Results of the Dissertation:

1. In the field of transportation management, the use of technologies such as the Intelligent Transport System (ITS) under the concept of smart mobility and various solutions for eliminating the causes of traffic congestion have been analyzed.
2. In the case of Baku city, methods proposed for optimizing traffic flow and promoting the use of public transportation in the northern part of the city, which is the main entry-exit point and experiences the most intense traffic congestion, have been studied.
3. The potential application of the proposed neural network model for predicting the average traffic speed in various fields has been explored. Using the test corpus based on 7,920 observations from VVDSs installed at 22 points on 8 streets and avenues in Baku, it has been determined that the proposed method offers better analysis and prediction capabilities for effective traffic management and road safety.
4. As a result of the research, it has been confirmed that neural networks and artificial intelligence, particularly abstract algorithms, can be effectively used in predicting the average traffic speed to address the causes of traffic congestion. The findings allow for the assessment and identification of the risk of traffic congestion.
5. During the research, a model for predicting the average traffic speed of motor vehicles in cities, developed using Baku as an example, yielded positive results with an error rate of 4.52% in the

corresponding test corpus. These results demonstrate that the proposed method works independently in a real environment and confirm the importance of a larger database for future research, allowing for the application of more complex and improved neural networks that yield better results.

6. The advantages of applying smart mobility methods and the benefits of managing city public transportation have been noted. It has been determined that these methods, along with the use of technologies like ITS, are effective in reducing traffic congestion and addressing its causes.

7. It has been determined that the results of the research can be used to predict the average traffic speed of streets or avenues without VVDSs or detectors.

8. With the help of the proposed solutions, it will be possible in the future to organize the "green wave" mode adaptively during peak and non-peak hours, weekends, holidays, and any time period.

9. Based on the research, a project for the organization of the "green wave" mode was developed for Matbuat Avenue and Academic Zarifa Aliyeva Street in Baku, and this project has already been implemented on Matbuat Avenue with positive results.

10. Economic justification results showed that in Academic Zarifa Aliyeva Street, reducing traffic congestion and delays, increasing the average speed, as well as reducing fuel consumption of vehicles and saving time, would lead to an expected economic benefit of 284,156 AZN over the course of one year.

**The main provisions of the dissertation are reflected in the following published scientific works:**

1. Bağırov, M.İ. Şəhərdaxili yollarda avtobusların sol zolaqda hərəkətinin və yolayrıclarında sola və ya geri dönmələrinin ləğv edilməsi // Qloballaşma və regional inteqrasiya Respublika Elmi Konfransı, – Mingəçevir: Avrora nəşriyyatı, – 23–24 dekabr, – 2016, s. 316-317.

2. Bağırov, M.İ. Nəqliyyat vasitəsinin dayanmasının qadağan olunduğu yolayrıcı ("sarı qutu") // Doktorantların və gənc

tədqiqatçıların XX Respublika Elmi Konfransı, – Bakı: – 2016, s. 296-298.

3. Bağırov, M.İ. “D” kateqoriyasına daxil olan avtonəqliyyat vasitələrini idarəetmə hüququna malik sürücülərin məsuliyyətinin artırılması // Azərbaycan xalqının ümummilli lideri Heydər Əliyevin anadan olmasının 94-cü ildönümünə həsr olunmuş tələbə və gənc tədqiqatçıların “Gənclər və elmi innovasiyalar” mövzusunda Respublika Elmi-texniki Konfransı, – Bakı: AzTU-nun mətbəəsi, – 3–5 may, – 2017, s. 322-323.

4. Əhmədov, H.M., Bağırov, M.İ. Dairəvi hərəkətin təşkil olunduğu bəzi yolayrıclarında hərəkətin tənzimlənməsinin təkmilləşdirilməsi // Azərbaycan beynəlxalq nəqliyyat sistemində: məqsədlər və perspektivlər Beynəlxalq elmi və praktiki Konfransı, – Bakı: Azərbaycan nəşriyyatı, – 2–5 oktyabr, – 2018, s. 110-113.

5. Bağırov, M.İ. Şəhərlərarası taksi dayanacağı // Azərbaycanın nəqliyyatı: Nailiyyətlər, problemlər və perspektivlər, – Bakı: AzTU-nun mətbəəsi, – 16–17 aprel, – 2019, – s. 100-103.

6. Bağırov, M.İ. Əliyev, İ.M. Logistik əhəmiyyətli və əhalinin sıx olduğu ərazilərdə avtostansiyaların təşkili // Azərbaycanın nəqliyyatı: Nailiyyətlər, problemlər və perspektivlər, – Bakı: AzTU- nun mətbəəsi, – 16–17 aprel, – 2019, – s. 39-41.

7. Bağırov, M.İ. Bakı şəhərinin mərkəzi hissəsində (“Hökumət Evi”ətrafında) yol hərəkətinin təşkilinin təkmilləşdirilməsi // – Bakı: Azərbaycan Respublikası Təhsil Nazirliyi, Azərbaycan Memarlıq və İnşaat Universiteti Elmi Əsərlər, – 2019. №2, – s. 59-65.

8. Bağırov, M.İ. Bakı şəhərinin şimal giriş-çıxışında nəqliyyat axınlarının tənzimlənməsi // – Bakı: Azərbaycan Respublikası Təhsil Nazirliyi, Azərbaycan Memarlıq və İnşaat Universiteti Elmi Əsərlər, – 2019. №1, – s. 130-135.

9. Bağırov, M.İ., Avtovağzal ərazisində piyadaların və nəqliyyat vasitələrinin hərəkətinin təhlükəsizliyinin təmin edilməsi üsulu, İxtira i2020 0041, Azərbaycan Respublikası / – 2020.

10. Baghirov, M.I. Prediction of recommended traffic speed for green wave regime using an artificial intelligence method // Progressive research in the modern world. Proceedings of II

international traffic and practical Conference, – Boston: BoScience Publisher, – 02–04 November, – 2022, – p. 93-98.

11. Baghirov, M.I. Developing a coordinated regulation schedule to prevent damage to the environment by vehicles and improve the structure of the energy system: evidence from the city of Baku // – Kiev: Journal of Automobile transport. Collection of scientific Works, – 2023. №52, – p. 64-70.

12. Baghirov, M.I. Establishment of Confidence Intervals for Average Vehicle Speeds // – Istanbul: Journal of Traffic And Transportation Research, – 2023. №2, – p. 131-142.

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