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Ph.D. THESIS
SUMMARY

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CONTRIBUȚII LA IMPLEMENTAREA UNOR NOI SOLUȚII DE CONTROL AL TRAFICULUI AUTO

CONTRIBUTIONS TO THE IMPLEMENTATION OF NEW TRAFFIC CONTROL SOLUTIONS

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Chapter 1

Introduction

Nowadays, with the evolution and development of cities and living conditions, it is observed that other consequences appear, such as the agglomeration of urban areas, through the increase in population, the increase in the number of cars in traffic, and respectively the congestion of vehicle traffic. Congested traffic also means problems related to a high level of pollution in large urban agglomerations, i.e. increased fuel consumption for motor vehicles, all of which lead to health and environmental problems, especially respiratory problems due to air quality.

This work aims to introduce and analyze a field that affects us all, namely transport, respectively traffic, and based on it we can analyze and improve vehicle traffic, respectively solutions can be proposed to improve traffic. As technology evolves, new ideas and solutions emerge that can lead to much faster and more efficient solutions to existing problems.

1.1 Presentation of the field of the doctoral thesis

The topic addressed in this paper, namely vehicular traffic, generally refers to the movement of various vehicles on roads. By the name of vehicle is meant any means of transport used for the movement of a person or goods, including here as examples cars, trucks or motorcycles.

The movement of vehicles on a road can be influenced by a lot of different factors, such as road infrastructure, traffic rules on a certain section of road, weather conditions that can differ from day to day or the behavior of drivers.

Traffic and its control are important nowadays considering the following:

1. Traffic is essential for the functioning of localities, especially cities because it is closely related to the transport of both people and goods, thus being able to affect the economy;

2. The quality of urban mobility affects the lives of citizens, given the stress and time spent in traffic;

3. Traffic is also a big source of pollution in big cities;
4. Traffic control increases both the efficiency and safety of any traffic participant, whether they are a vehicle driver, a pedestrian or a cyclist.

1.2 Scope of the doctoral thesis

This research in this thesis aims to present contributions to the implementation of new car traffic control solutions, along with the advantages and limitations of each. For these researches, various tests and experiments were implemented with these traffic control methods which are described in the following chapters.

Traffic control methods, whether based on classic systems (such as traffic lights with fixed schedules) or intelligent solutions (such as adaptive ones based on sensors, artificial intelligence or predictive models), have a direct impact on the quality of urban life. Effective control of intersections can reduce congestion, contribute to lower fuel consumption and pollution levels, and increase road safety.

Traffic congestion is a current and future problem in large urban agglomerations, large cities, as the number of people in them increases, the number of cars participating in traffic increases, and the simple improvement of road infrastructure is not enough in many cases and innovative methods are needed to be able to decongest traffic. Over time, with the appearance of the first vehicles and the first signaling systems and traffic rules, various methods of traffic control appropriate to the times appeared. Nowadays, however, with the advance of technology, with the appearance and advance of artificial intelligence, new innovative solutions appear that can lead to better traffic control, which is adaptable and responds quickly to any unforeseen traffic event.

1.3 Content of the doctoral thesis

The PhD thesis focuses on the implementation and evaluation of new existing traffic control solutions, their testing and experimentation, respectively on the analysis of consequences related to congested traffic through pollution monitoring. Various solutions are also analyzed and proposed to be able to both monitor traffic and make drivers aware of the consequences of different driving styles. This thesis is structured in 7 chapters as follows:

Chapter 1 presents the studied field, the purpose and respectively the content of the doctoral thesis through the general presentation of the chapters.

Chapter 2 presents the history of traffic control systems. Also in this chapter, the main urban traffic control systems are presented, they are analyzed from the point of view of advantages and limitations, and to demonstrate the efficiency of such a traffic system, simulations were carried out in a special traffic simulation program.

Chapter 3 presents the main pollutants from traffic congestion, carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and fine particles (PM2.5 and PM10). Considering the importance of pollution, an electronic system based on two modules has been created and implemented that can be placed in key areas within a city and can monitor and transmit to a user the values for the most important indices, the PM2.5 and PM10 parameters. Thus, this chapter will present details related to the creation of the electronic air quality monitoring system that consists of two distinct modules, the components used and the results obtained from the tests. At the same time, in this chapter, an analysis of traffic and traffic intersections from the perspective of information theory will be carried out and presented, and notions such as entropy, probability, distributions in the case of traffic and intersection characterization will be presented.

Chapter 4 introduces traffic models, their characteristics, and how they can predict traffic by determining speed, traffic density, or traffic flow. Also, an electronic module responsible for the acquisition of traffic data, namely GPS coordinates, will be presented, and its components, respectively the realization and implementation, will be discussed step by step. The data acquired with this module was used to implement various traffic models to be able to predict the speed with their help and test their accuracy. Also, in the last part of this chapter, these traffic models will be implemented and compared for the case of a highway being analyzed, where the speed and density values are known to be different from the case of a city.

Chapter 5 presents the field of machine learning, respectively the algorithms that can be used in predicting traffic and the average traffic speed according to different situations and conditions. Traffic cases analyzed with the help of the main automatic learning algorithms will be presented, respectively they will be compared based on the results in order to identify the most suitable automatic learning algorithm according to the type of problem analyzed and its characteristics.

Chapter 6 presents a system for improving traffic safety and monitoring pollution level by implementing the concepts of reward system and blockchain. A reward system capable of rewarding or penalizing a driver based on driving style in traffic was designed, using various parameters from the vehicle retrieved via OBD-II, with the aim of analyzing the driver's behavior in traffic. Also, based on the data provided by the vehicle through the OBD-II device, the main pollutants emitted by a vehicle following its use at city level are estimated (by determining the values of carbon dioxide(CO_2), nitrogen oxides(NO_x), respectively carbon monoxide (CO)).

Chapter 7 of this thesis presents the conclusions of the paper, summarizing the results obtained over the years of doctoral studies, together with the conferences and papers in which the obtained results were presented.

Chapter 2

History of traffic systems

Over time, vehicular traffic and road infrastructure have seen a major transformation, evolving from simple paths without any regulation or rule to extensive road networks and sophisticated traffic management systems. This development has been shaped by a combination of inventions, innovations, and social and economic demands and has been made over hundreds of years throughout history. Vehicle traffic analysis plays an essential role in addressing contemporary challenges, allowing the development of creative solutions to streamline traffic, reduce the impact of pollution and increase road safety.

Nowadays, modern cities face many challenges related to traffic management, environmental impact and efficiency of urban infrastructure. The challenge of traffic congestion is one of the most pressing, affecting not only the daily mobility of citizens, but also air quality, the economy and public health [5]. The rapid expansion of urban areas and population growth are generating a volume of traffic that exceeds the capacity of existing networks, and the challenge of adapting the infrastructure to these demands is becoming increasingly difficult.

2.1 The evolution of urban traffic control systems

With the advent of motorized vehicles and their widespread spread, the problem of traffic control arose. The systems developed over time for this purpose are part of what are called urban traffic control systems (in English they are called UTC - Urban Traffic Control).

UTC (Urban Traffic Control) systems are advanced solutions for the intelligent management of urban traffic, optimizing the movement of vehicles through the dynamic adjustment of traffic lights. These systems collect and analyze data in real time, using sensors and equipment installed on the main arteries of cities, allowing a quick reaction to traffic variations, incidents or special conditions. Through the use of intelligent algorithms, traffic lights are coordinated to reduce congestion, waiting times and polluting emissions, contributing to a more efficient and friendly urban environment.

2.1.1 The emergence of control systems with fixed planes

The first stage in the evolution of UTC traffic control systems is between 1920 and 1980. During these years, with the appearance of electric traffic lights, but also with the appearance of more vehicles that led to traffic congestion, the basic objectives that a traffic control system must have were established.

Thus, fixed-plan traffic control systems emerged, which follow a predetermined plan linked to the traffic lights at an intersection. To be able to achieve this coordination of traffic lights through this type of system, it was necessary to define each zone of an intersection in a region, and then to optimize the traffic lights through the most important parameters established, namely [17]: cycle time, split time and compensation time.

2.1.2 The emergence of traffic adaptive control systems

The second stage in the evolution of UTC traffic control systems is from the late 1970s to the present day. Thanks to the technological advance, new solutions have been reached to be able to monitor and manage traffic. Inventions and innovations that have changed the way UTC systems work include inductive loops, radar and infrared detection technology.

Among the most advanced UTC systems used globally are:

SCOOT (Split Cycle Offset Optimization Technique) – Developed in the UK, this system adjusts traffic lights in real time, using inductive detectors to adapt traffic flow without depending on pre-set plans [18].

SCATS (Sydney Coordinated Adaptive Traffic System) – Created in Australia, it provides decentralized control of traffic lights, allowing each intersection to adjust individually, but in a coordinated manner with the entire system [4].

UTOPIA (Urban Traffic Optimization by Integrated Automation) – Developed in Italy, it stands out for its advanced integration with public transport and other urban infrastructure, using predictive models to anticipate and prevent congestion [13].

These systems help streamline traffic, improving road safety and urban efficiency.

In order to be able to test the efficiency of these UTC systems, within the article [14], simulations were carried out in the PTV Vissim traffic program. PTV Vissim is a microscopic traffic simulation program created by PTV Planung Transport Verkehr AG in Karlsruhe, Germany. This important tool is widely used in transportation engineering to model and analyze different traffic scenarios.

Thus, the following data and results are from the article presented and mentioned above [14], and in the following it will be detailed what the experiment consisted of and the results that were obtained. In using this program, another important advantage for PTV Vissim is that it has integrated within it a controller for the SCOOT traffic control system, so that it is possible to optimize the cycle times of a traffic light, the times for the green color of a traffic light in an intersection or the delay times required to manage an intersection [10]. The test with the help of this program was done for an intersection in Bucharest, the intersection between Iuliu Maniu boulevard and Doina Cornea boulevard. In order to perform the simulation, measurements and results from the article [9] were used.

The intersection in question, for which the simulations and measurements were carried out, was marked in the public and free OpenStreetMap application. This includes road infrastructure details, then the intersection highlighted in OpenStreetMap will be imported into PTV Vissim. In the following figure, figure 2.1, you can see the map of the intersection together with the existing infrastructure, in the program used.

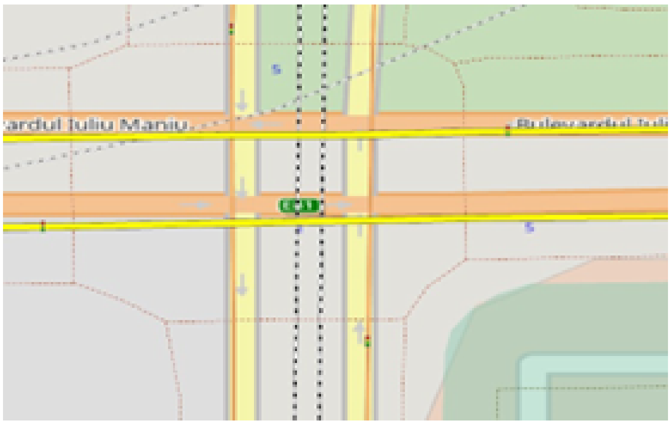

Fig. 2.1 The intersection used for simulation in PTV Vissim [14]

Also, a more in-depth examination of the intersection is available in the PTV VISSIM program, highlighting that all road infrastructure details are included, as can be seen in figure 2.2.

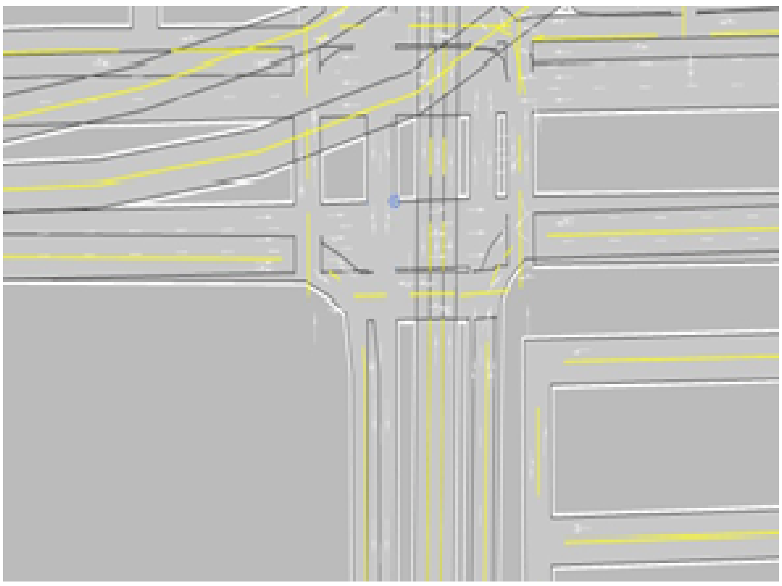

Fig. 2.2 Intersection with road infrastructure details [14]

In the previously mentioned study [9], measurements were taken daily, for 60 minutes, between 10-11 am, over ten days. These measurements allowed the determination of traffic conditions, the number of cars crossing the intersection on Iuliu Maniu Boulevard, and the average speeds of vehicles. All these details were later integrated into the imported intersection in PTV Vissim.

After integrating a SCOOT [10] controller into the PTV VISSIM software program, simulations were carried out to evaluate the traffic condition and average car speeds on the said boulevard. The results of these simulations, shown in figure 2.3, show the average speeds before and after the application of the SCOOT system, as well as the actual traffic recorded. It can be seen that the SCOOT system improves traffic, leading to an increase in average speed.

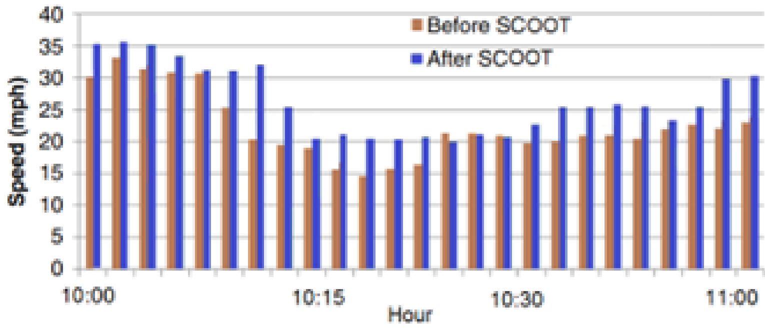

Fig. 2.3 Comparison of average speed before and after SCOOT application [14]

Chapter 3

Vehicle Pollution Monitoring and Intersection Analysis

Modern cities are experiencing an important increase in the number of vehicles, which leads to major problems related to pollution and congestion. Traffic-generated pollution affects air quality, contributing to respiratory and cardiovascular diseases. Also, fine particles and greenhouse gases produced by vehicles contribute to climate change, and their effect is constantly observed from year to year, the average temperature of the planet increases, so the effects are felt. These climate changes have a very big impact on the environment, thus affecting the air we breathe, the temperature at the level of the planet, the acidification of the soil and water (so that the soil becomes less fertile for agriculture, and the water ends up no longer drinkable), the destruction of the ozone layer (being thus exposed to ultraviolet rays), as well as the impact on biodiversity (many species of animals end up being in danger of extinction).

3.1 Sources of pollution and the main pollutants

Vehicles generate a complex spectrum of emissions, classified into two distinct categories: direct and indirect. Direct emissions, resulting from the burning of fossil fuels in internal combustion engines, include pollutants such as carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and fine particulate matter (PM2.5 and PM10). Diesel engines, in particular, are notable for their increased emission of fine particles and nitrogen oxides, contributing significantly to urban air pollution. Indirect emissions, on the other hand, are generated by related processes such as the wear and tear of tires and braking systems, as well as the production and distribution of fuels. Studies in high-traffic areas have shown a direct correlation between high concentrations of fine particles and the negative impact on the health of the local population.

3.2 Electronic air quality monitoring system

The role of this module is to collect data from sensors related to air quality, process it and send it both to a database and to the second module where are received and can be viewed on an alphanumeric liquid crystal display. The block diagram for this module can be seen in the following figure, with all the components used.

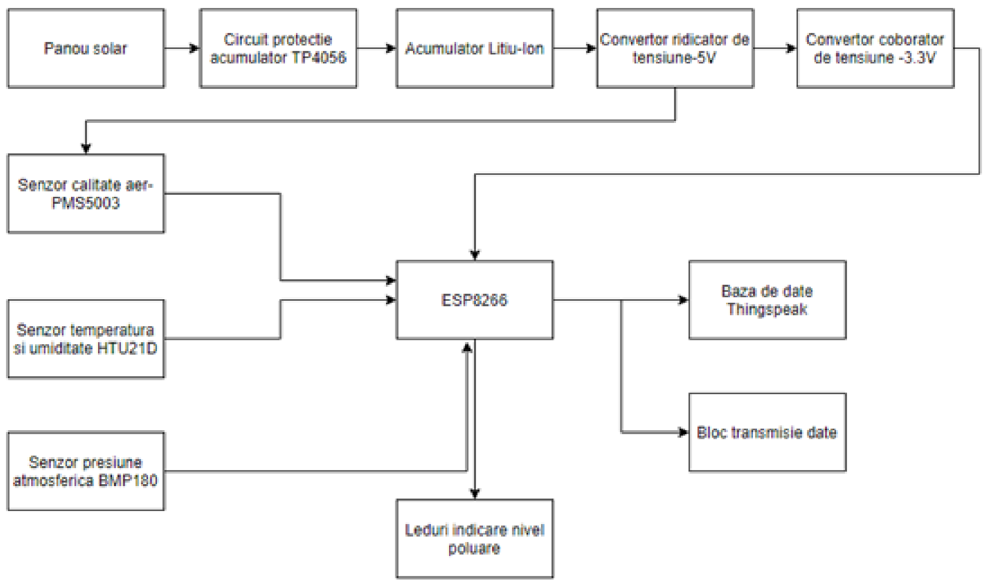

Fig. 3.1 Block diagram for the transmission module

From the functional point of view, in the center of the block diagram you can identify the microcontroller used, ESP8266, taking the data from the three sensors located on the left side (the air quality sensor PMS5003 which will provide the values for PM2.5 and PM10, the temperature and humidity sensor HTU21D and the atmospheric pressure sensor BMP180). The microcontroller is responsible both for retrieving the data from the sensors, and for processing them and transmitting the data to a database (Thingspeak personal account) and to the second module, the data reception and display module. From the power point of view, the component blocks can be seen at the top of the block diagram. The components of the electronic board are powered by a Lithium-Ion 18650 battery, and this battery is in turn charged by a photovoltaic panel. Since the Lithium-Ion 18650 battery has a maximum supply voltage of 4.2V, to protect the battery and ensure the operational safety of the entire module, the TP4056 protection circuit was used, with the role of limiting the charging to the maximum value of 4.2V. Also, since the maximum electric voltage of the accumulator is 4.2V, and some components in the circuit need an electric voltage of 5V, a voltage step-up converter was used, with the output value of 5V. At the same time, the ESP8266 microcontroller and part of the sensors work at 3.3V electrical voltage, and therefore a step-down converter with a fixed output value of 3.3V was also used. In addition, in the block diagram you can also see the LEDs with the role of indicating the level of pollution (3 LEDs of different colors are added, green, yellow and red) and whose meaning is as follows: the green LED lights up when the concentration of PM2.5 particles is between 0 and 20 µg/m³, indicating a low level of pollution, the yellow LED signals a moderate level of pollution, being active when the PM2.5 value falls within between 20 µg/m³ and 30 µg/m³, and the red LED warns of a high level of pollution, lighting up when the PM2.5 concentration exceeds 30 µg/m³.

3.3 The module for receiving and displaying data

The first electronic module has been detailed and described in the previous subsections. Related to the second electronic module, its role is to receive data related to air quality and atmospheric conditions, and display them to the user, regardless of where he is, not being conditioned by a specific location in relation to the other module. In the following figure, you can see the block diagram for this part of the system:

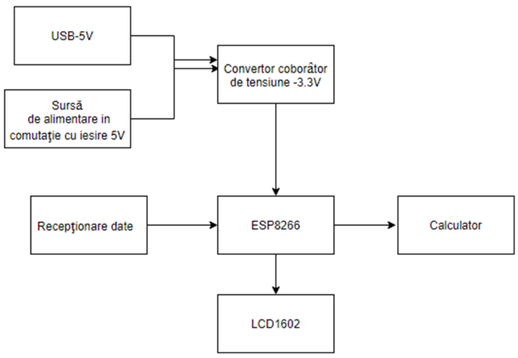

Fig. 3.2 Block diagram for data receiving and display board

Like the previous board, the ESP8266 microcontroller is centrally positioned. It, being connected to a local wireless network, takes the data from the other board and transmits it to a display, whose operation will be described later. At the same time, the device offers the possibility of being connected to a computer.

In terms of power, the board can be powered either through the CH340 USB converter, also used for programming the microcontroller, or through a switching power supply, which provides a 5V output. It is important that this power supply is equipped with a standard 5.5x2.1mm round male plug. To program the two microcontrollers, a device capable of converting between the USB and serial interface of the microcontroller was used. This conversion is done by the CH340 converter, which has a USB plug at one end and the necessary pins for connecting to the microcontroller at the other. The CH340 converter was described along with its characteristics in the previous chapter. Since the microcontroller requires a supply voltage of 3.3V, a step-down converter has been included to meet this requirement.

3.4 The practical implementation of the two modules and the results obtained

Following the practical implementation of the two modules were obtained, the final results can be seen in figures 3.3 and 3.4.

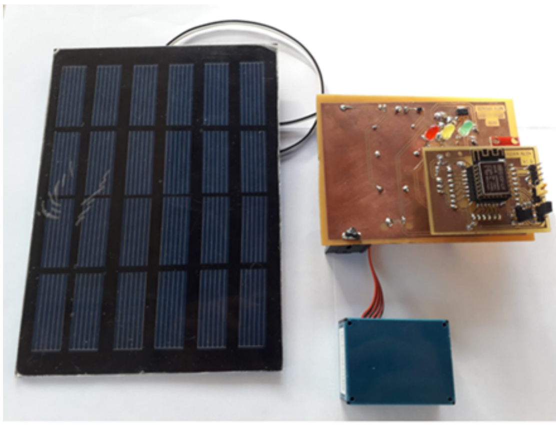

Fig. 3.3 Processing and transmission board

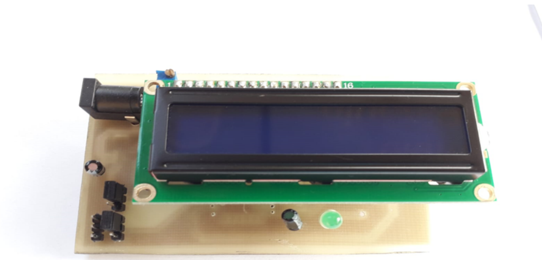

Fig. 3.4 Reception and display board

Chapter 4

Traffic Models and Data Acquisition

Traffic flow models are mathematical tools designed to describe how vehicles move on a road network. They are essential to study and interpret traffic dynamics, providing valuable data on vehicle density, speed and flow [6].

They allow the simulation of real scenarios and the evaluation of the impact of interventions on traffic. Traffic flow models are fundamental in understanding and optimizing road traffic. They can be used for a variety of purposes such as:

- Predictive simulations for anticipating traffic behavior in different situations;
- Road infrastructure planning, helping to design and expand intersections and roads based on forecasts of traffic volume in a given area;
- Real-time traffic optimization by dynamically adjusting traffic light cycles;
- Evaluation of the impact on the environment, which can be used in the estimation of pollutant emissions;
- Road safety, by analyzing the results of traffic patterns, critical points where accidents frequently occur can be identified and preventive measures can be implemented, such as speed limits or the installation of additional signs.

4.1 The electronic module for the acquisition of traffic data

To be able to analyze the traffic in a certain area and to have statistics, respectively the traffic patterns explained in the previous sub-chapter, it was necessary to generate traffic data. With this goal in mind, an electronic module presented in the [16] article was designed, an electronic device that will acquire GPS data, record it and send it for analysis and application of traffic models. From the construction point of view for this electronic module, its block diagram can be seen in figure 4.1:

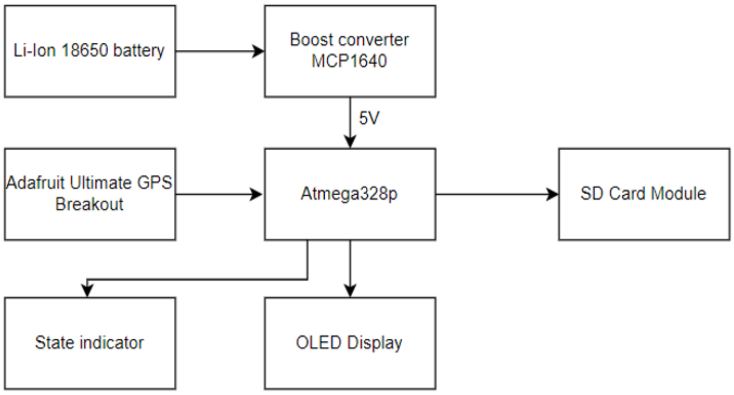

Fig. 4.1 Block diagram of traffic data acquisition mode [16]

In terms of power supply, a Lithium-Ion 18650 battery was also used, similar to the one used in the electronic module for air quality monitoring and which was presented in the previous chapter. Also related to the power supply, since the maximum electrical voltage of such a battery is 4.2V, and the components in the electronic module work at 5V, a step-up converter was used; this is the MCP1640 and was also presented in the previous chapter, along with the details of operation and the resistors chosen in the resistive divider to provide the 5V output voltage.

4.2 Creation of the electronic module

The previously described electronic module was physically realized and in figure 4.2 it can be seen assembled with all the components:

Fig. 4.2 The electronic module in the final version - top view

4.3 Electronic module testing and implementation of traffic models

Once the module was created, the testing part followed. The data obtained from the electronic module were used to implement the traffic models, and the results can be seen in the following table. In order to be able to evaluate the performance of the traffic models for the data used, the difference between the values provided by the model and the real ones, MAPE, the mean absolute percentage error, was used, and its formula can still be seen in the equation (4.1) [1]. Table 4.1 shows the results obtained, and Pipea obtained the best result for the analyzed situation.

$$MAPE = \left| \frac{1}{N} \sum_{i=1}^{N} \frac{|v_{act} - v_{est}|}{v_{act}} \right| \times 100 \tag{4.1}$$

where v_{act} and v_{est} represent the current and actual speed, and N represents the number of logs.

Traffic model used	v_f	k_j	v_c	Equation	MAPE value
Greenshields	43.2	100.2	21.6	$v = 4324\left(1 - \frac{k}{1002}\right)$	0.0789
Greenberg	-	130.4	20.4	$v = 20.4 \cdot \ln\left(\frac{130.4}{k}\right)$	0.0823
Underwood	52.3	-	26.1	$v = 52.3 \cdot e^{-\left(\frac{k}{512}\right)}$	0.0934
Pipes	42.8	90.3	21.4	$v = 42.8\left(1 - \left(\frac{k}{90.3}\right)^5\right)$	0.0712

Table 4.1 The results after applying the traffic models

4.4 Application of traffic models in highway regime

In order to be able to compare the traffic models, a comparison of them was also made on data obtained from traffic at the highway level. For this purpose, public data from the National Highways of England website about the A2 and from 2014 was used. This traffic database contains information on date and time, traffic flows (in vehicles per hour), and speed values (in miles per hour). So, since this data only contains values for traffic flow and speed, and in the models that will be used speed and traffic density are needed, to be able to prepare the data for the application of the models, the fundamental equation (4.2) was applied between the standard quantities in the traffic so as to obtain the traffic density [11]:

$$q = u \cdot k \tag{4.2}$$

where q is the traffic flow, u is the velocity, and k is the traffic density.

Based on the traffic patterns analyzed and the R^2 results obtained, the following results were extracted from table 4.2, where it can be seen that the Drake model achieved the best results.

Table 4.2 Comparison of traffic model parameters

Traffic flow model	u_f Km/h	k_j Veh/km	u_c Km/h	k_c Veh/km	R^2
Greenshields	119.2	150.4	59.6	75.2	0.76
Underwood	122.4	-	61.2	73.4	0.80
Greenberg	-	180.4	28.7	55.11	0.61
Drake	123.4	-	73.9	106.23	0.91
Robertson	120.5	140.3	64.2	84.5	0.74
Van Aerde	121.8	138.2	62.3	83.2	0.70
Northwestern	122.8	-	71.4	85.6	0.88

Chapter 5

Predicting traffic and speed using machine learning algorithms

Machine learning is a branch of artificial intelligence that allows systems to improve their performance based on experience, without the need for explicit instructions from a programmer. This progress is possible due to the huge amount of data available today, allowing machines to be trained rather than simply programmed.

Machine learning technologies are increasingly being applied in modern road traffic control systems, with the potential to significantly reduce congestion in large cities. Unlike classical methods based on fixed rules or rigid traffic light programming, machine learning algorithms can continuously analyze data collected from the field and adapt control strategies according to the dynamic traffic context. This data can come from a variety of sources, such as inductive sensors embedded in the road, video cameras, GPS systems installed in vehicles, mobile applications or intelligent V2X (Vehicle-to-Everything) infrastructures.

Based on this information, machine learning models can predict traffic values in different areas of the road network, detect in real time the formation of congestion and offer solutions to optimize flows. For example, algorithms such as recurrent neural networks or LSTM (Long Short-Term Memory) models are used to predict short-term traffic flow evolution, while reinforcement learning methods can be applied to adaptively adjust traffic light cycles depending on intersection conditions. At the same time, convolutional networks allow the interpretation of video images for the automatic detection of incidents or unusual behavior of vehicles.

Combining these approaches results in systems capable of quickly reacting to changes in traffic, more efficiently distributing vehicle flows and reducing waiting time at intersections. The direct effects are visible in reduced journey times, reduced fuel consumption and greenhouse gas emissions, as well as increased road safety. Additionally, these systems can learn from past behaviors and constantly improve the decisions made without requiring manual reprogramming.

A key challenge remains the integration of these technologies into an existing infrastructure, often outdated or lacking digital connectivity. Also, data quality and real-time processing speed are critical factors for model performance. However, as cities become more interconnected and autonomous vehicles begin to drive alongside conventional ones, machine learning will become a fundamental element in orchestrating a smart, adaptive and sustainable urban mobility system.

5.1 Machine learning algorithms used

In traffic forecasting, machine learning algorithms are used to analyze historical and real-time data, providing accurate estimates of vehicle flow, travel times and potential congestion. These algorithms can be divided into several categories, these being the ones presented before.

Within the article [15], the following machine learning algorithms were used: Decision Tree, Support Vector Machine (SVM) and Random Forest.

5.2 Case studies for machine learning algorithms in traffic

The presented algorithms along with related metrics were used in the evaluation of various traffic problems that were presented in the [15] article at the 2022 14th International Conference on Electronics, Computers and Artificial Intelligence (ECAI). For the implementation of these algorithms, traffic data was needed, and these are GPS data, the acquisition and processing of which was presented in the previous chapter; for these case studies, $GPRMC type messages were used, which contain the essential information for the algorithms and their implementation, namely location (latitude and longitude), speed and time respectively. In the following image, figure 5.1, you can see the area of interest from where the data were collected, with the starting point on the left and the arrival point on the right.

Fig. 5.1 Area of interest for data acquisition [15]

In this published work, several situations were analyzed using the previously presented machine learning algorithms: vehicle speed was studied relative to the time of day, approaching this situation as a regression problem. Speedvariation by day of the week was also examined, along with an analysis of vehicle speeds in traffic and a calculation of the level of traffic congestion.

Regarding the first mentioned situation, namely vehicle speed according to the time of day (between 8:00 and 20:00), the training and testing of the algorithms generated specific values for the evaluation metrics. Based on the analysis of this situation and the application of machine learning algorithms, treating this problem as a regression one and applying the appropriate metrics, the following results were obtained:

Table 5.1 The results of the evaluation metrics for the first analyzed problem [15]

Algoritm	R^2	MSE	RMSE	MAE
Support Vector Machine	0.72	8.86	2.97	4.92
Random Forest	0.80	6.10	2.46	3.10
Decision Tree	0.82	6.23	2.49	3.68

The best result based on the metrics can be seen that the results are similar, with Decision Tree obtaining slightly better values for the metrics used in the performance analysis.

For the second situation analyzed, with determining the speed based on the day of the week, this situation was analyzed as a classification problem. The three algorithms presented in this chapter were applied, and then the performance evaluation metrics were applied to a classification problem. Table 5.3 shows the results obtained by the evaluation metrics for each algorithm:

Table 5.2 Evaluation metrics results for the second problem analyzed [15]

Algorithm	Accuracy	Precision	Sensitivity	F1 Score
Decision Tree	78%	73.45%	73%	73.22%
Support Vector Machine	77%	75.12%	72%	73.53%
Random Forest	81%	79.45%	74%	76.63%

It can be seen from this table that the Random Forest learning algorithm achieved the best results for all performance evaluation metrics, with the other two algorithms performing similarly.

Chapter 6

Improving traffic safety and reducing emissions through a reward system and blockchain

Road traffic has grown considerably in recent decades, and this growth has brought with it safety concerns, both in the short term, such as accidents and traffic jams, and in the long term, such as deteriorating air quality or health problems caused by prolonged exposure to harmful emissions. These issues have been addressed through policies and regulations with varying success. Until recently, most policies and regulations targeted the industrial sector, but nowadays most road traffic problems are generated by individuals. Vehicular traffic, especially in congested cities, has a significant impact on the emissions footprint of each individual and exposes drivers and pedestrians to increased risks caused by aggressive traffic behavior, especially in urban environments.

In order to be able to improve traffic safety, as well as monitor and reduce pollutant emissions from vehicles, a reward system was designed, in which real traffic data was acquired and used for a blockchain-based reward system. From the point of view of the pollutants monitored and whose quantity was estimated by various methods, these are the ones that were explained and used in chapter 3 of this paper, carbon dioxide(CO_2), carbon monoxide(CO) and nitrogen oxides(NO_x).

6.1 Acquisition of data from vehicles

To be able to realize the whole system it was necessary to acquire real data during the driving session. Therefore, data was acquired from the vehicle via an OBD-II device that will connect and send data via Bluetooth technology to an app on a mobile phone. OBD-II (On-Board Diagnostics II) is a standardized vehicle diagnostic system used to monitor and report essential parameters of the engine and other critical components. OBD-II is a self-diagnostic system that monitors the performance of the engine and auxiliary systems. It collects and reports data on emissions, fuel, engine parameters and more through a standardized [12] diagnostic port.

The method of data acquisition, respectively the way the entire system works can be seen in the following figure, figure 6.1. Thus the data from the vehicle is received via OBD-II and reaches the application installed on the phone, and then can be sent to the blockchain system.

Fig. 6.1 Scheme of the system used

6.2 Reward system implemented

A reward system is an organized mechanism designed to encourage the occurrence of desired behaviors by providing benefits in response to the achievement of certain objectives or compliance with certain requirements. Based on theories of motivation and positive reinforcement learning, such a system finds varied applications, from education and business to digital technologies or urban traffic management. Thus, the implementation of a reward system involves clearly establishing the targeted actions, tracking their achievement and granting benefits that reflect their fulfillment. Rewards can take the form of material goods, such as money, discount coupons, products, or symbolic elements, such as badges, titles of honor or access to special functions [2].

Within this project and system, the integration of the reward system makes the use of blockchain technology an ideal option. The digital tokens of the network can be transformed into an ERC-20 virtual currency, which serve as a reward mechanism, so that depending on the behavior of a driver in traffic, he can be rewarded or penalized [3].

The proposed solution bases its reward component on a system of calculating points, which are either added or subtracted from the user's account after each driving session. The process is enabled by an algorithm of the reward system, which evaluates the speed of the vehicle compared to the limit imposed within the area in which it travels. Based on this analysis, points are adjusted according to the (6.1) equation, helping to encourage responsible traffic behavior.

$$p_s = \begin{cases} 1, & \text{dacă } \Delta s < 0 \\ 0, & \text{dacă } \Delta s \in [0,5) \\ -3\log_2\left(\frac{\Delta s}{5}\right), & \text{dacă } \Delta s \geq 5 \end{cases} \tag{6.1}$$

where

$$\Delta s = \text{current speed} - \text{limit speed}$$

This formula defines a reward function according to the variation of the speed Δs, having the following interpretation:

- For the first case, if $\Delta s < 0$, then $p_s = 1$, this means that when the speed value decreases (for example, a driver reduces consumption or emissions from a reference threshold), the user receives the maximum possible reward, one point;
- In the second case, if $\Delta s \in [0,5)$, i.e. Δs is positive but small (less than 5 km/h), then $p_s = 0$, the driver does not receive any points;
- In the third case, if the difference $\Delta s \geq 5$, the user is penalized. Because the logarithm is applied to a fraction $\frac{\Delta s}{5}$ and then multiplied by -3, the result will be negative and decrease as Δs increases.

This formula builds a performance-based reward system, so the driver is encouraged to obey the legal speed limit, and speeding over that limit results in the user being penalized, and the penalty increases in a logarithmic fashion (so not linear, but progressively more severe as impairment increases). Using the logarithmic function makes the penalty relatively "gentle" at first, but increases more rapidly as Δs increases. The threshold of 5 km/h is chosen as a limit between tolerance and penalty.

In the figure 6.2 you can see a graphic representation of the rewards system:

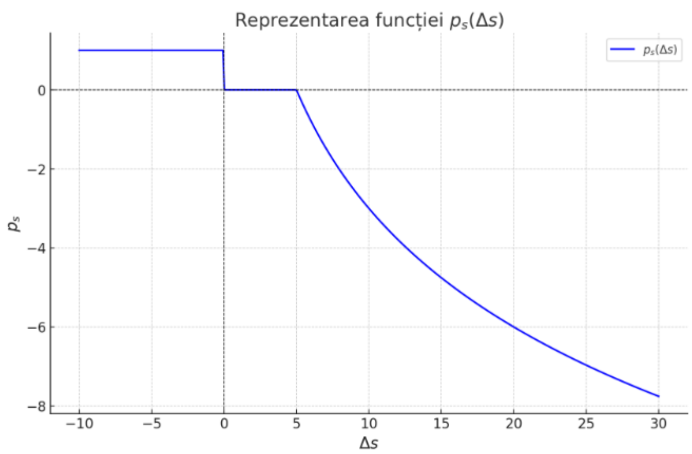

Fig. 6.2 Graphic representation of the reward system

6.2.1 Testing the implemented system and the results obtained

To validate the proposed solution, it was tested using a Ford Kuga 2023 vehicle, equipped with a 1.5L gasoline engine and having an emission rate of CO_2 of 148.95 g/km according to WLTP standards [7], [8]. Several races were organized on similar routes in comparable traffic conditions. Each route included two distinct driving sessions: one characterized by an aggressive and inefficient driving style without speed limit compliance and no fuel consumption concerns, and the other oriented towards a moderate and optimized driving style with an emphasis on speed limit compliance and fuel economy. Both sessions were run in similar traffic, weather and time of day conditions. Table 6.1 provides an overview of the characteristics of the two driving sessions. Figures 6.2 and 6.3 illustrate the routes traveled in the two sessions and the corresponding air quality. Observations indicate a lower air quality in the first session compared to the second. Table 6.1 provides an overview of the characteristics of the two driving sessions.

Table 6.1 An overview of the driving sessions

Driving style	Distance (km)	Time (min:sec)	Medium speed (km/h)	Engine speed (rpm)	Medium consumption	Ideal speed changes
Normal	19.04	32:35	34.25	1485.28	2.13	96.02
Agresiv	12.50	27:24	26.59	1550.39	2.32	82.19

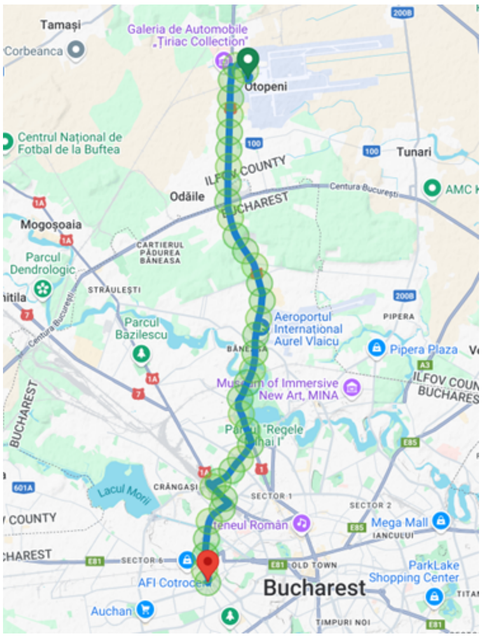

Fig. 6.3 Route for normal driving style

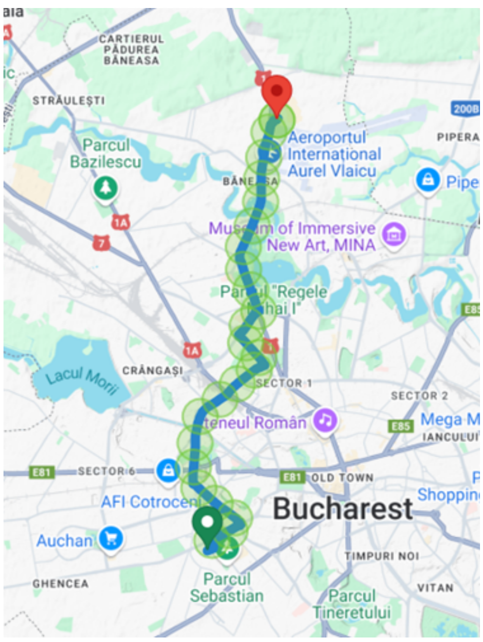

Fig. 6.4 Route for aggressive driving style

Fig. 6.5 Routes used for driving styles

Based on the three pollutant estimation methods and which were explained in the previous subchapter, for the two driving sessions, were the results in tables 6.2 and 6.3. It can be seen that method 3 obtained the best results, close to reality because it takes into account all the chemical reactions between the substances involved and uses mass air flow.

Table 6.2 Estimates of emissions using the methods presented for normal driving

Pollutant	Method 1	Method 2	Method 3
CO_2 g/km	120.12	145.21	149.45
CO g/km	0.21	0.31	0.78
NO_x g/km	0.003	0.03	0.04

Table 6.3 Emissions estimates using the methods presented for aggressive driving

Pollutant	Method 1	Method 2	Method 3
CO_2 g/km	130.22	147.54	150.21
CO g/km	0.41	0.64	1.35
NO_x g/km	0.005	0.04	0.05

Considering what was previously presented in this chapter, it can be concluded that the reward system is beneficial for road safety by helping drivers to become aware of their driving style. Also, such a system is also useful in the case of monitoring pollutant emissions such as those presented and calculated in this chapter: CO_2, CO, and NO_x.

Chapter 7

Conclusions

This doctoral thesis had as its main objective the implementation and evaluation of new traffic control solutions considering the development and growth of cities in terms of population and the number of vehicles participating in traffic. With the advent of vehicles and the first signaling systems and traffic rules, traffic has changed significantly, so that control and monitoring solutions appropriate to the times have emerged over the years. In the current situation, the traffic in big cities is in a continuous transformation, driven by both the accelerated urbanization and the increase in the number of vehicles, the need for sustainable mobility, so the identification of efficient or intelligent methods of traffic management becomes essential.

Road traffic is not just a simple aspect of everyday life, it is an important element to consider when analyzing a city. Vehicle traffic reflects economic vitality, where social activities are concentrated, how easily people move and how developed cities are. If traffic is well organized, everyday life becomes easier, stress decreases, things move faster and the environment is better protected.

7.1 Obtained results

Chapter 1 presents the field of the doctoral thesis, the purpose, respectively the content of the doctoral thesis.

Chapter 2 presents the history of traffic and the most important traffic control systems. Simulations were also carried out in a special traffic simulation program and the obtained results are presented.

In chapter 3, the main polluting substances are presented, respectively the electronic system created for the purpose of monitoring the level of pollution is described. The constituent components are presented, the final results together with the tests and experiments carried out. Also, an analysis of traffic and traffic intersections from the point of view of information theory was carried out and presented.

Chapter 4 presents the traffic models along with their characteristics, respectively an electronic module responsible for the acquisition of traffic data. The obtained data were used to implement and test the traffic models described.

In chapter 5, the automatic learning algorithms are presented, respectively different traffic cases analyzed with the help of the main automatic learning algorithms in order to identify the most suitable algorithm according to the type of problem analyzed and its characteristics.

Chapter 6 presents a system for improving traffic safety and monitoring the level of pollution by implementing the concepts of reward system and blockchain.

In chapter 7, the conclusions of this thesis are presented, along with the results obtained, the conferences where the works were presented, respectively the future development perspectives.

7.2 Original contributions

Among the original contributions in this work we mention:

1. Configuration and creation of a simulation test of the SCOOT traffic control system within the PTV Vissim program[4];

2. The design and implementation of an electronic system capable of monitoring air quality and atmospheric conditions so that the level of pollution within a city is continuously observed[1];

3. Creation of an electronic module for the purpose of acquiring traffic data for later use[5];

4. Evaluating information theory concepts in traffic and intersection analysis[2];

5. Configuration and implementation of traffic models for the situation in which traffic is analyzed at the city level, respectively at the highway level[5];

6. Implementation of machine learning algorithms to predict the average traffic speed according to different situations and conditions[3];

7. Creation and implementation of a blockchain-based reward system to improve traffic safety and increase awareness of the consequences of a vehicle's driving style[1];

8. Evaluation of different methods of estimating the emissions of a vehicle based on the parameters provided by it via the OBD-II device[1];

7.3 List of original publications

The results obtained and presented in this doctoral work have been published in the following conferences and journals:

1. Serban, AA; Frunzete, M, "Electronic System for Monitoring Quality of Air and Atmospheric Conditions with Autonomous Power Supply System", International Symposium on Fundamentals of Electrical Engineering (ISFEE), NOV 05-07, 2020, Univ Politehnica Buchares, Bucharest, ROMANIA, pp: 1-4, ISBN: 978-1-7281-9038-9, DOI: 10.1109/ISFEE51261.2020.9756153, WOS:000812321500023

2. ŞERBAN, A. A., & FRUNZETE, M. (2021, July). Data obtained from vehicle to manage traffic control. In 2021 International Symposium on Signals, Circuits and Systems (ISSCS) (pp. 1-4). IEEE.

3. Şerban, A. A., & Frunzete, M. (2022, June). Statistical analysis using machine learning algorithms in traffic control. In 2022 14th International Conference on Electronics, Computers and Artificial Intelligence (ECAI) (pp. 1-4). IEEE.

4. Şerban, A. A., & Frunzete, M. (2022, October). Analysis and comparison between urban traffic control systems. In 2022 IEEE 28th International Symposium for Design and Technology in Electronic Packaging (SIITME) (pp. 92-95). IEEE. WOS:000947243400022

5. ŞERBAN, A. A., & Frunzete, M. (2024, September). Traffic flow models and statistical analysis using compressed data from acquisition module. In 2024 Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA) (pp. 183-187). IEEE.

6. Zîrnă, B. A., Mihailovschi, D., Şerban, A. A., & Frunzete, M. C. (2024, September). Design of a Portable EMG and ECG Signal-Based System for Upper Limb Recovery Using Data Compression. In 2024 Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA) (pp. 109-114). IEEE.

7. Serban, A. A., Marghescu, C. I., & Drumea, A. (2018, October). Sensor Module for Monitoring Atmospheric Pressure, Temperature and Humidity With Autonomous Power Supply System. In 2018 IEEE 24th International Symposium for Design and Technology in Electronic Packaging(SIITME) (pp. 361-364). IEEE. WOS:000466960400077

8. Șerban, A. A., Drumea, A., & Marghescu, C. (2019, October). Electronic module for carbon monoxide monitoring and warning. In 2019 IEEE 25th International Symposium for Design and Technology in Electronic Packaging (SIITME) (pp. 146-170). IEEE. WOS:000564733700030

Articles currently being published:

1. Bogdan Cristian Florea, Alin Alexandru Serban, Dragos Daniel Taralunga(2024 December). Blockchain-Driven Gamification Solution for Improving Road Traffic Safety. In 2024 9th International Conference on Information Systems Engineering (ICISE2024), ISBN: 979-8-4007-1736-9

Articles submitted for acceptance and publication:

1. Bogdan Cristian Florea, Alin Alexandru Șerban, Dragoș Daniel Țarălungă, Mădalin Corneliu Frunzete, Blockchain-Driven Gamification Solution for Road Traffic Safety and Emissions Regulation, MDPI Applied Sciences

2. Alin Alexandru Serban, Mădalin Corneliu Frunzete, Corneliu Burileanu, Comparative analysis of macroscopic traffic flow models on highways, UPB Sci. Bull., Series C

Research reports:
4 scientific research reports within SD-ETTI:

1. Scientific report no. 1/2021, Sistem electronic pentru monitorizarea calității aerului și a condițiilor atmosferice cu sistem de alimentare autonom (Electronic system for monitoring quality of air and atmospheric conditions with autonomous power supply system)

2. Scientific report no. 2/2021, Date obținute de la vehicul pentru a gestiona controlul traficului (Data obtained from vehicle to manage traffic control)

3. Scientific report no. 3/2022, Analiză statistică folosind algoritmi de învățare automată în controlul traficului(Statistical analysis using machine learning algorithms in traffic control)

4. Scientific report no. 4/2022, Analiză și comparație între sistemele de control ale traficului (Analysis and comparison between urban traffic control systems).

Projects in which the student participated:

1. ARUT 2023 - Compression algorithm for medical signal storage recorded with wearable devices(Algoritm de compresie pentru stocare de semnal medical înregistrat cu dispozitive de tip wearable), MedCS (ID: 220235152)

7.4 Perspectives for further developments

The problem of congested traffic is a current problem that is still not solved because according to TomTom and the statistics presented since the introduction, traffic is congested in big cities and people waste a lot of time in traffic to move from one area to another.

With the rise of the smart vehicle, equipped with advanced technology and able to interact with the Internet, another important aspect must be taken into account these days, namely data security and protection against unauthorized access. Such modern cars not only collect and transmit information, but also integrate a complex network of elements, including dozens of electronic control units (ECUs), sensors, CAN communication networks, Wi-Fi connectivity, Bluetooth, and advanced mobile networks such as 4G and 5G. Moreover, remote software updates facilitate the constant improvement of functionalities, but also increase the associated risks.

Also from the point of view of development perspectives, apart from data security, the speed of data transmission from and to smart vehicles must also be taken into account, so the 5G network represents a safe and efficient solution because it has a very low latency (of about 1-10 ms), high bandwidth and the ability to connect a large number of mobile devices simultaneously. Thanks to these functionalities, vehicles can establish direct and continuous communication both with each other and with the elements of the road infrastructure (Vehicle-to-Everything – V2X), which considerably increases road safety and helps to streamline traffic.

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