ЕЛЕКТРОННО СПИСАНИЕ „ИКОНОМИКА И КОМПЮТЪРНИ НАУКИ“, БРОЙ 2, 2019,
ISSN 2367-7791, ВАРНА, БЪЛГАРИЯ
ELECTRONIC JOURNAL "ECONOMICS AND COMPUTER SCIENCE", ISSUE 2, 2019,
ISSN 2367-7791, VARNA, BULGARIA

Improving the work of traffic lights by using real-time control system software

Boyan KARAKOLEV[1]

[1] University of Economics, Varna, Bulgaria
boyankarakolev@ue-varna.bg

Abstract. Traffic problems are inherent to urban movement worldwide. Effective management of traffic control devices is the main instrument for dealing with these problems. The aim of this article is to suggest a model of a software product for real-life traffic light control and thus optimize traffic. Designing the model and its practical implementation would inevitably result in reducing traffic jams and cutting the time motorists spend behind the wheel. This in turn would lead to considerable economic and environmental benefits for the population of the city.

Key words: traffic, congestions, traffic lights, control system software.

1. Introduction

Traffic lights are the main instrument for the regulation and control of urban traffic. The effective work of these systems leads to reducing traffic jams, raising the average vehicle speed, cutting the time spent travelling and lowering the number of road accidents. The morally obsolete methods of programming and control of intersection traffic lights that are widely used in Bulgaria are unable to respond to the needs of the growing numbers of automobiles. It is only in the last few years that in some large cities (Sofia and Varna) measures have been taken to modernize traffic light equipment, but these are still not effective enough. The aim of this article is to suggest a model of a software product for real-time traffic light control, which will help optimize traffic under the existing limitations of the urban environment.

2. Problems of urban traffic

Over the last few decades there have been serious traffic problems in large cities worldwide (Katwijk *et al.*, 2005), as a result of the continuous growth of urban population and the ever-increasing number of automobiles moving across the urban road network, respectively. This is due to the migration of the population from smaller towns and villages to large cities. Over the last two centuries the earth's population has increased 6 times, while over the same period the numbers of city dwellers have grown 60 times. The tendency of a growth in urban population is expected to last for the following years as well, and a report (McKinsey Global Institute, 2012) estimates that by the end of 2025 the world urban population will increase by another 1.2 billion people. The growing numbers of city dwellers require additional living space. This entails a change in the settlement structure directed at the territorial expansion of large cities.

Parallel to the trend of increasing urban population, another process takes place – that of the growing number of automobiles in cities across Bulgaria, as well as worldwide. According to a research of the International Energy Agency (IEA, 2012), over the period 2000 – 2010 the number of automobiles across the world has increased tenfold: from 4 automobiles per 1000 people to 40 automobiles per 1000 people. This dynamics is expected to be active in the following years, too, and in 2035 there will be 310 automobiles per 1000 people (see Fig.1). The local statistics show that in 2016 in Bulgaria (Eurostat, 2016) , there are more than 440 vehicles per 1000 people, and this value is similar to the average in the Europe Union. According to a third source (the meeting of the biggest car producers in Qatar (Hamprecht, 2012), the number of automobiles on the world roads is expected to rise over 4 times: from 700 million at present to the impressive 3 billion!

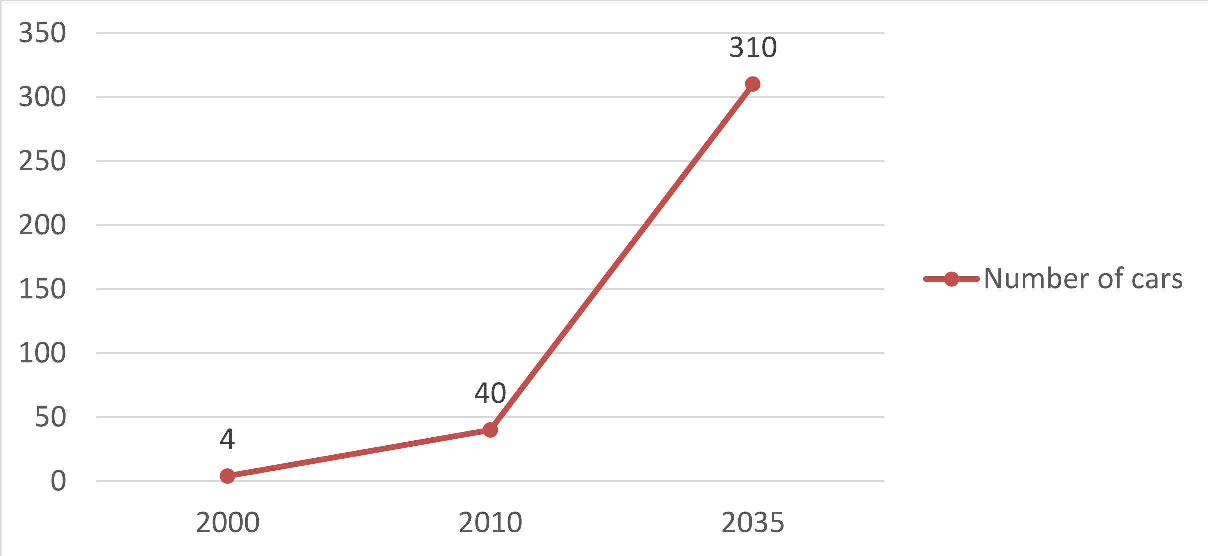

Figure 1. Number of cars per 1000 persons worldwide

The increase in the number of automobiles and the excessive road network overload result in huge economic and social losses. The significance of the problem is determined by the large numbers of casualties and injured in road accidents and the resulting economic losses sustained. It is necessary to ensure safe road environment by reducing the number of traffic accidents. According to data published in the World Health Organization’s annual Global status report on road safety for 2018, approximately 1.35 million people die in traffic accidents worldwide every year (World Health Organization, 2018). Road accidents also feature as the main cause of disability with approximately 50 million injured each year, and are the leading cause of mortality for people aged between 15 and 29. The said report makes it clear that the financial losses from road crashes cost medium- and low-income countries, such as Bulgaria, between 1 and 2% of their gross domestic product. According to another research, also included in the same WHO report and carried out in 178 countries accounting for 98% of the world population, it turns out that in one single day 3287 people worldwide die in road traffic accidents and the number of injured amounts to 140 000 people a day, of which 15 000 sustain lasting damages as a result of the accident. Many of the countries featuring in the research lack the relevant legislation to fight road deaths: only 15% of these countries have adopted the regulations to reduce the main risk factors on the road such as speeding, drinking-and-driving, failure to use child car seats, telephone conversations while driving, failure to fasten car seat belts, etc. WHO data show that nearly half of the road traffic deaths are those of cyclists and pedestrians and statistic indicates that car crashes are among the leading causes of young people mortality.

According to data for 2018 of WHO in the Global status report on road safety, more people are dying as a result of road traffic injuries than from HIV/AIDS, tuberculosis and diarrhoeal diseases.

Traffic jams are another major problem resulting from the ineffective management of urban traffic. The urban road network overload is one of the main transport problems that affect large cities worldwide. A reference concerning the world’s 30 biggest cities prepared by the consulting firm “Roland Berger” (Roland Berger, 2013) shows that the annual economic and social losses these cities sustain, due to road congestion, amount to 266 billion USD. Cities all over the world are trying to cope with the problems of the urban traffic overload resulting from the growing demand and the inability to build adequate road infrastructure to meet the growing needs.

The ever-growing flow of automobiles in central urban areas causes frequent traffic jams and the trend is on the increase each year. In Sofia, for example, there were 71 000 newly registered cars in 1998. Over a period of 10 years, their number has grown nearly 5 times to reach 350 000 in 2008. The last few years have seen an increase in the number of passenger automobiles per 1000 persons from the population of Bulgaria (Eurostat, 2015) (see Fig.2). In view of the objective character of this analysis, it should be noted that the growth in the numbers of newly registered cars is not directly proportional to the number of car owners, due to the social inequality among Bulgarian population.

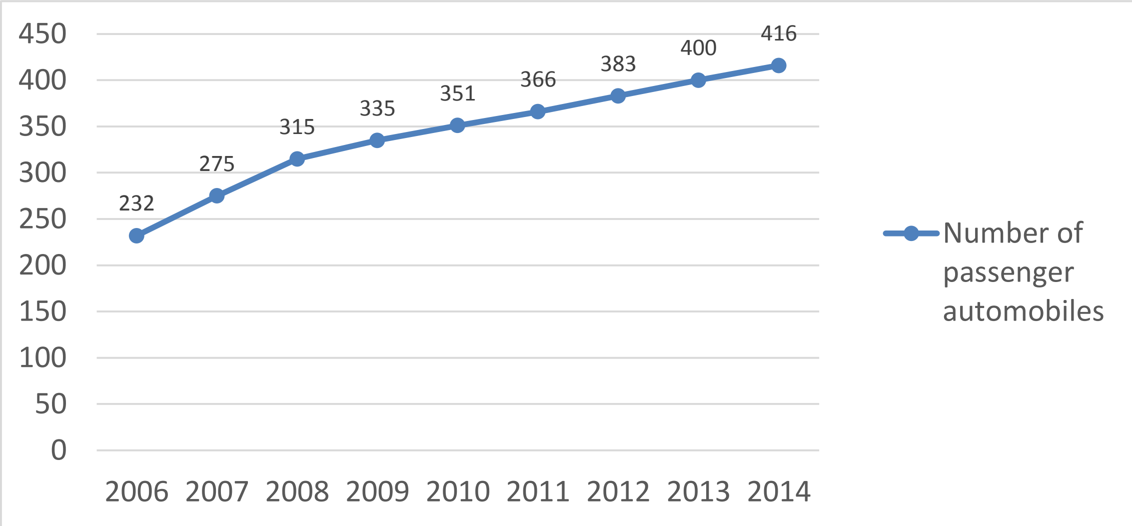

Figure 2. Number of passenger automobiles per 1000 persons in Bulgaria

The growing number of automobiles results in the increase of traffic jams in large cities with the problem aggravating because of the fact that these cities’ street network was not designed to accommodate the traffic levels of today. A large part of urban road pavement is in poor condition, which slows traffic down and entails frequent traffic jams and delays. The number of car owners is growing at rates that are faster than those of street infrastructure and traffic management systems being modernized and restored.

Along with the tendency of increasing the number of automobiles, another trend is observed - that of the growth of urban population, which further raises the concentration of automobiles in large cities and deteriorates the problem of traffic jams in city central zones. According to data from a research by (IBM, 2012), it is believed that, under conditions of growing globalization, by the year 2050 70 per cent of world population will live in the cities.

In order to optimize traffic in large cities and define an arterial road as a heavily loaded, and also in order to make a decision on the need to implement additional software solutions to regulate traffic, it is necessary not only to study traffic along the particular road, but also analyze the underlying causes for this traffic: where and why this traffic is generated, what determines motorists’ choice of driving along this particular road, what are the future prospects of drawing further traffic to this arterial road. In Bulgaria, by law, these activities are performed exclusively by the Central Institute of Road Technologies, National and European Regulations and Standards (the Central Roads and Bridges Laboratory), which every 5 years performs measurements of mostly intercity traffic. The research of the institute gathers data on the number of passing vehicles but without analyzing frequency of travel or choice of travel route. Practically, the lack of sufficient data makes it difficult to research the problem of city traffic network overload in this country and take relevant measures to regulate this load.

There does not seem to be a single and straightforward solution to the problems described above. The traffic control tools are created to bring security measures – to prevent having 2 vehicles at the same time on the same place (Gazis, 2017). Despite that around 10 years ago there were not enough researches of these issues, due to the complexity of the matter (Guo, 2009), nowadays a lot of algorithms, paradigms and traffic control simulators already exist (Chedjou and Kyamakya, 2018). Information technologies can function as a possible instrument for dealing with these problems, but they are, as it was mentioned before, unable to solve the problem entirely. Yet they can lead to a lasting improvement in urban traffic, particularly when they are combined with an adequate improvement in road infrastructure. According to some researches (Al-Qadi, I., Sayed, T., Alnuaimi, N., Masad, 2008) the improperly setup traffic control instruments are causing between 5 and 10 per cent of the congestions in the cities. They also claim that the investment in improvement of these instruments is giving 40 times revenue.

In this connection, we suggest a model of a software product for the automated management of traffic control devices, whose development and implementation would lead to a most noticeable improvement in urban traffic. The model provides an effective solution to the problem of the high volume of vehicles and the traffic jams they create, these congestions being an inseparable part of the daily life of a big city.

3. Model of a software product for traffic light management

There are 3 different ways to control the time schedule of the traffic lights – predefined, semi-automated and fully-automated (Sfetcu, 2014) . Despite that it is well known that the fixed time schedule is ineffective because it is impossible to predict the traffic’s dynamics (Chen, Y., Yao, J., He, C., Chen, H., Jin, 2017), the traffic light controllers that are widely used both in Bulgaria and worldwide are working exactly this way. This schedule contains a preliminary set fixed period of time for the green signal for the various phases every hour. The choice of the time period of the phases of a traffic light controller is made on the basis of statistical data on traffic density. This approach, though relying on real data concerning vehicle traffic, cannot cope with the increasingly overloaded urban road network.

This is why in the last several years the semi-automated solutions in this field are gaining popularity, relying on self-organization (Prothmann *et al.*, 2011). In these intelligent transport systems that cope with traffic jams and increase the average speed of automobiles, are used different means for receiving information about the state of the car traffic in real time. The said information is collected by a centralized software system which analyzes it and, if necessary, makes adjustments in the traffic light controllers work mode. As a main disadvantage of such systems, some authors (Boel and Marinica, 2015) say that their internal algorithms are so complicated that from the user’s point of view, it is too hard to intuitively understand what will happen after a certain change in infrastructure or the traffic.

On this basis, we will offer a system that will have minimum complexity, but despite that will be able to deal with the challenges of the urban traffic control. The most important functionality that this programming product contains is real-time regulation of the traffic lights work mode, which is achieved by means of a sequence of operations. These basic steps are presented as a scheme in Fig.3.

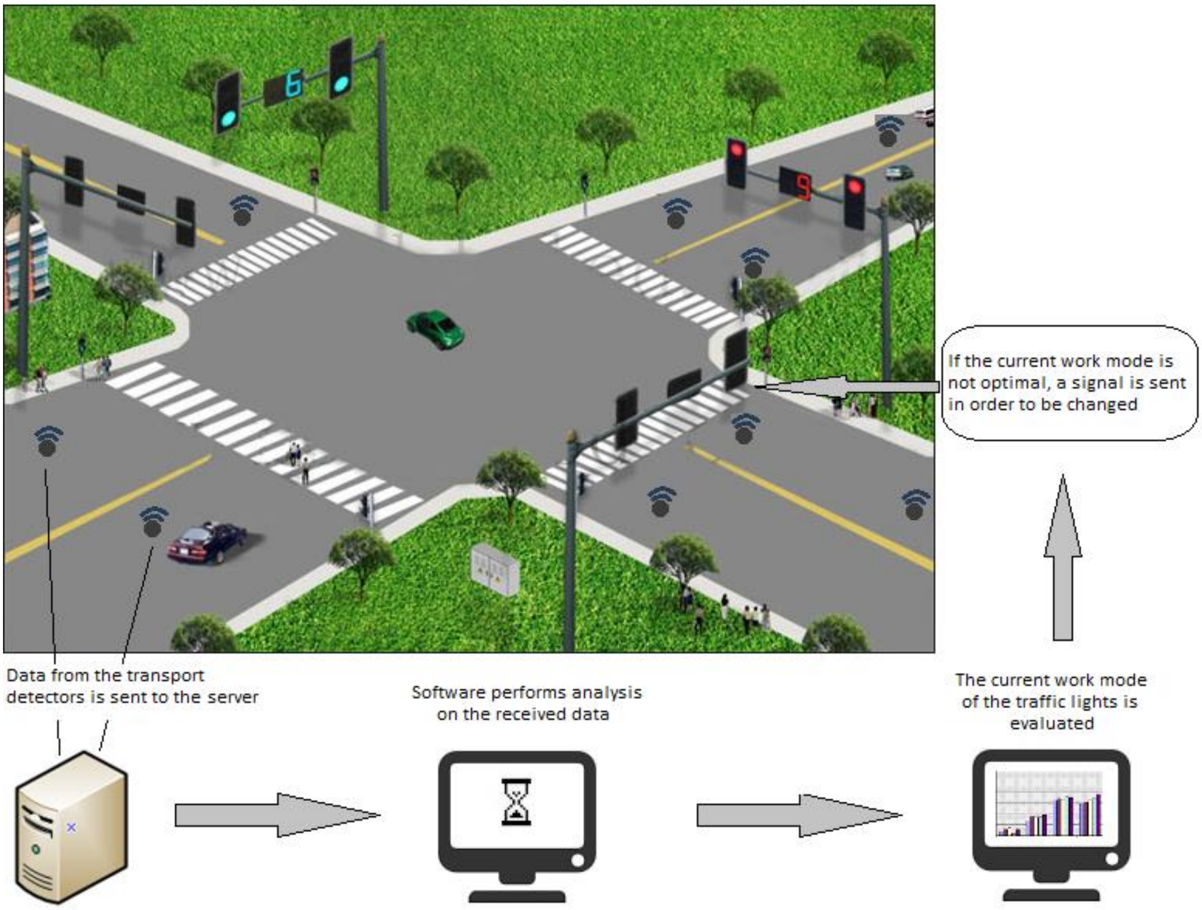

Figure 3. A scheme of how the traffic light control module functions
Source: Own elaboration

• Initially the system receives data about the volume of traffic in real time, which come from the transport detectors mounted at intersections;

• Software performs analysis on the received data and defines the density volumes for the different directions of the intersection;

• The data are compared to data coming from neighbouring intersections, so that the expected transport flow to each intersection can be determined;

• The optimal work mode for the traffic light at a given intersection is defined not only based on the state of the intersection itself, but also taking in consideration the overall state of traffic at its neighbouring intersections;

• If the optimal work mode for the particular traffic lights differs from its current mode, a command is sent to change the parameters of traffic lights functioning.

Owing to the facilities that the software product provides, the performance of traffic lights across the city can be boosted. By means of this software correlation between two neighbouring intersection takes place in real time. This allows for an adequate and timely reaction to a change in traffic intensity. For example, in case of a considerable crowd of automobiles at a certain intersection, most often close to city entrances, depending on the destination they follow, we can establish where is the next intersection cars will end up at and in what time. The traffic light control at the said intersection will be prepared for a change in traffic by modifying its work mode, and in particular, a change in the signal program it follows, which has been performed automatically by the central control module.

In order for the software system for traffic light control to function, it is necessary to make sure that information on traffic conditions is received in real time. To this end, there need to be used technical devices for reporting on the traffic in question, which should be mounted at the intersections themselves. These can be induction frames, camcorders and other, depending on the software solution chosen. The received information should be stored and for that purpose we suggest the building and usage of a relational database. Fig 4 presents a scheme of the tables where information necessary for the functioning of the traffic light control software will be recorded.

We suggest the following content of the tables in the DB and the way they are going to be used by the management system.

One of the basic tables in the database is the “Traffic_lights” table. This is a nomenclature table describing all the controlled intersections that exist in a particular settlement and the traffic light controls that are mounted there.

In another nomenclature table – “Green_waves” are recorded the sequence of intersections with their starting point and ending point, for which a green wave is provided, in case traffic conditions allow that. When the records for a particular green wave are retrieved and arranged by their serial number, the result is a sequence of intersections along which the traffic lights should ensure a green signal for passing cars.

Each one intersection contains several destinations and road lanes. Information about them is stored in the tables “Traffic_lights_destinations” and “Road_lanes” respectively. Destinations come as vehicle destinations and pedestrian destinations, each belonging to a type described in the nomenclature table “Types_of_destinations”. They are go straight, right turn, left turn, U-turn, pedestrians crossing and should be described for each street of the intersection. A destination can contain one or more road lanes. This is one of the reasons why data are divided into two tables to which another one is added to stipulate the relations between the two – “Road_lanes_by_destination”. Each destination of movement is determined by a direction, which is recorded in a “Directions” table.

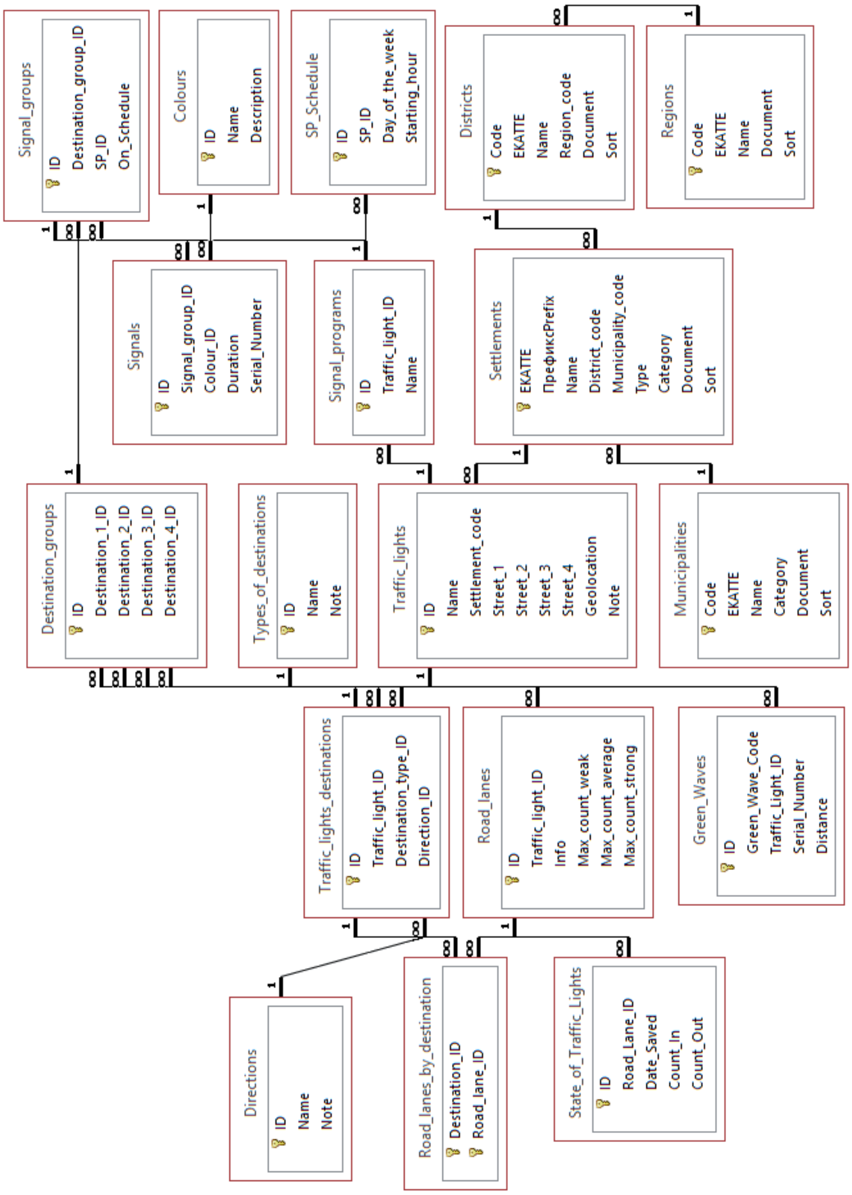

Figure 4. Relational diagram of the module DB
Source: Own elaboration

Another reason for separating road lanes from destinations of traffic is the devices that count the number of cars at the intersection at any given moment. They gather information on automobile traffic for each separate lane, and this information is directly recorded in the “State_of_Traffic_Lights” table. Information about all surveyed lanes of all regulated intersections should enter the DB every 10 seconds. If during the process of analysis, it is found out that a shorter or longer time period is necessary, this can be adjusted.

After this information arrives, it is compared to what is available in the “State_of_Traffic_Lights” table for this particular intersection in order to define whether there has been a change in traffic intensity. If a change is reported, based on the data received, the module performs the necessary calculations in order to establish whether at this particular moment vehicle traffic is optimal or it needs to be optimized. This analysis is performed by means of comparing the results of the calculations with the current settings of the traffic lights controllers. For this purpose, it is necessary that the DB should contain information on the current work modes of all traffic lights.

Traffic light controllers are managed by means of traffic signal programs. Each signal program defines which destinations of traffic at any given moment have the right-of-way at the intersections and which ones do not. The signal programs (SP) themselves are recorded in the table of the same name in the DB, where each SP consists of the so-called Signal Groups (SG). They determine which destinations receive the same signals of regulation. A single SG may refer to one or more destinations. This is shown in the “Destination_groups” where up to 4 destinations of a given traffic lights can be grouped together. Thus all of them receive the same signal for crossing an intersection. For example, destinations of this type can be opposing destinations of going straight or right, which most often simultaneously receive a green signal. For each SG, a sequence of signals is available and these signals are recorded in the “Signals” table. The next number field shows the sequence of turning on the signals. Start is from the first signal in the row and after its pre-set time is up, the signal is off and is replaced by the next one. Signal execution takes place in loops, i.e. after the last signal the process starts all over again.

The table “SP_Schedule” contains the pre-set schedule according to which traffic lights are managed. It is possible to select a particular day and hour when a given signal program is used. The signal programs schedule is created based on experience accumulated over the years and is used when traffic does not need to be optimized. This is exactly how almost all of the traffic light controllers in Bulgaria work at present.

The last four DB tables have been borrowed from the Single Classifier of administrative-territorial and territorial units in Bulgaria (Edinen klasifikator na administrativno-teritorialnite edinitsi v Balgaria – EKATTE[24]). EKATTE is supported by the National Statistical Institute (NSI[25]) under agreement with the Ministry of Regional Development and Public Works (Ministerstvo na regionalnoto razvitie i blagoustroistvoto – MRRB[26]) by virtue of art. 37, par. 1 of the Law on Administrative-Territorial Structure of the Republic of Bulgaria (LATSRB). As of 9.12.2018 EKATTE includes 5256 settlements – 257 cities, 2 monasteries and 4997 villages. Settlements are grouped into 265 municipalities, 28 districts and 3187 local boroughs. This information was last updated on 19.01.2018.

In order to function, the suggested software product requires a stable server machine which is able to handle the huge volume of information and computations necessary for making decisions on the optimal traffic light management. We believe it is best to use a computer with a minimum 6core Intel Xeon E5 second generation processor, based on “Ivy Bridge EP” microarchitecture (Intel, 2012), with a minimum clock rate of 2GHz per each core. The machine needs a RAM of at least 16GB DDR3 and two hard disks installed, each with a minimum of 250GB memory, working in RAID1 mode. Under this mode information is simultaneously recorded on both disks with one disk being the mirror image of the other. Thus, better system security is achieved, as should one of the discs fail, work can continue uninterrupted. The suggested server would ensure the reliable and seamless work of the centralized traffic light management in the next 10 years. Its parameters are quite sufficient even if changes are made or new functionalities are added to the program.

The choice of a database management system (DBMS) of the traffic light management software system is based on the following evaluation criteria: security, speed and productivity, ability of the software to reflect the specifics of the developed system, easy maintenance, product price and maintenance price. Criteria are arranged in a descending order according to their weight in the formation of the overall evaluation.

As a possible choice providing speed, scalability, and free version could be a NoSQL DBMS such as MongoDB. Delivering load-sharing capabilities on different machines increases performance and productivity, but the ability to back up and restore is limited (Kuyumdzhiev, 2015a). We believe that the data stored in the system should be secure not only by malicious users but also by various forms of disasters and accidents that affect their integrity.

According to data published by db-engines.com (DB-Engines, 2018), “Oracle Database” and “SQL Server” are, respectively, the world’s first and third most popular DBMS. A key factor in choosing a DBMS is the highest possible level of security, as the application that is being developed directly impacts the way a town’s road network functions and the inviolability of the data contained in the application, as well as any chance of unauthorized access and alteration of data is of crucial importance for the local population. According to statistical data of the National Institute of Standards and Technologies in the USA (2012), since 2002 “SQL Server” has been the best-protected and secure database among all major producers. Regarding efficiency, a research by Softex (2013) points out that “SQL Server” causes less strain on the processor and consumes less memory[27]. As an added advantage, there are many tools developed by third parties to support the administrative tasks of backing up data (Kuyumdzhiev, 2015b).

For all these reasons, Microsoft’s “SQL Server DBMS has been chosen for the implementation of the software product for traffic controller management. Hence, the operating system of the server machine must be Microsoft’s “Windows Server 2016”. „SQL Server“ only runs on “Windows“ operating system, so we have chosen to use servers with the latest version of this operating system, as we expect a better level of security, speed of performance and better technical characteristics compared to the older versions of the operating system.

[24] http://www.ekatte.com/
[25] http://www.nsi.bg/nrnm/
[26] http://www.mrrb.government.bg/
[27] Tests have been carried out under Windows Server operating system.

The programming language we have chosen to write the application for traffic light management is “C++”. It is an object-oriented high-level language, which allows for a high degree of abstraction in creating applications. “C++” is designed for system and application programming. It has all the advantages of “C” (low level of abstraction and a great control over hardware), and at the same time includes classes and objects, multiple inheritance, virtual functions, polymorphism, templates, exception processing and embedded dynamic memory operators. The development environment chosen is one of the latest versions of Microsoft – MSVS 2017.

4. Conclusion

By far the major part of automobile traffic takes place in the urban environment. Millions of vehicles move across the world’s urban network every day. The examined problems of urban movement demonstrate the pressing need of measures being taken for improving the state of car traffic. The implementation of the suggested software product would reduce traffic jams and would shorten the time spent travelling in the cities, for both personal automobiles and public transport. The economic and environmental benefits deriving from this would be considerable. The resulting positive effect would be noticeable to motorists as well as pedestrians, citizens and tourists.

Literature

Al-Qadi, I., Sayed, T., Alnuaimi, N., Masad, E. (2008) *Efficient Transportation and Pavement Systems: Characterization, Mechanisms, Simulation, and Modeling*. CRC Press.

Boel, R. and Marinica, N. (2015) 'Leader–Follower Coordination Control for Urban Traffic', *Lecture Notes in Control and Information Sciences*, 456, pp. 35–44. doi: 10.1007/978-3-319-10407-2_5.

Chedjou, J. C. and Kyamakya, K. (2018) 'A review of traffic light control systems and introduction of a control concept based on coupled nonlinear oscillators', in *Studies in Systems, Decision and Control*. doi: 10.1007/978-3-319-58996-1_6.

Chen, Y., Yao, J., He, C., Chen, H., Jin, H. (2017) *Adaptive Traffic Signal Control with Network-Wide Coordination*, *Algorithms and Architectures for Parallel Processing: 17th International Conference, ICA3PP 2017*. Helsinki: Springer.

DB-Engines (2018) *DB-Engines ranking*. Available at: http://db-engines.com/en/ranking (Accessed: 9 December 2018).

Eurostat (2015) *Motorisation rate*. Available at: http://data.trendeconomy.com/dataviewer/eurostat/sd_pc_con/tsdpc340?kf=tsdpc340_DSD&time_period=2004,2005,2006,2007,2008,2009,2010,2011,2012,2013,2014,2015&geo=BG&unit=THS (Accessed: 17 October 2018).

Eurostat (2016) *Passenger cars in the EU*. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Passenger_cars_in_the_EU (Accessed: 12 December 2018).

Gazis, D. C. (2017) 'Contributions of Traffic Theory Toward Deployment of Intelligent Transportation Systems', *IFAC Proceedings Volumes*. doi: 10.1016/s1474-6670(17)43792-x.

Guo, H. (2009) *Automotive Informatics and Communicative Systems: Principles in vehicular networks and Data exchange*, *Chemistry & …*. doi: 10.4018/978-1-60566-338-8.

Hamprecht, H. (2012) *Challenges and opportunities in Qatar*, *Automotive News Europe*. Available at: http://www.autonews.com/article/20120127/BLOG15/301279997/challenges-and-opportunities-in-qatar (Accessed: 9 December 2018).

IBM (2012) *Smarter Cities*. Available at: http://www.ibm.com/smarterplanet/my/en/smarter_cities/overview/ (Accessed: 4 December 2018).

IEA (2012) *World Energy Outlook 2012*. Available at: https://www.iea.org/Textbase/npsum/weo2012sum.pdf (Accessed: 17 October 2018).

Intel (2012) *Ivy Bridge*. Available at: http://ark.intel.com/products/codename/68926/Ivy-Bridge-EP#@All (Accessed: 4 December 2018).

Katwijk, R. T. Van *et al.* (2005) 'Test Bed for Multiagent Control Systems in Road Traffic Management', *Transportation Research*.

Kuyumdzhiev, I. (2015a) 'Backup and recovery of MongoDB database: features, state, problems', *Izvestia Journal of the Union of Scientists -Varna. Economic Sciences Series*, pp. 125–133.

Kuyumdzhiev, I. (2015b) 'Primary methods and models to optimize backup and restore databases in MS SQL Server Express', *Vanguard Scientific Instruments In Management : Bulgarian Academic Simulation and Gaming Association (BASAGA)*, 11(2), pp. 56–61.

McKinsey Global Institute (2012) *Urban world: Cities and the rise of the consuming class*. Available at: http://www.mckinsey.com/global-themes/urbanization/urban-world-cities-and-the-rise-of-the-consuming-class (Accessed: 8 December 2018).

Prothmann, H. *et al.* (2011) 'Organic Traffic Control', in *Organic Computing — A Paradigm Shift for Complex Systems*. doi: 10.1007/978-3-0348-0130-0_28.

Roland Berger (2013) *Connected Mobility 2025*, *Think:Act*. Available at: https://www.rolandberger.com/publications/publication_pdf/roland_berger_tas_connected_mobility_e_20130123.pdf.

Sfetcu, N. (2014) *The Car Show*.

World Health Organization (2018) *Global status report on road safety 2018*. Available at: http://www.who.int/violence_injury_prevention/road_safety_status/2018/en/.