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THE DEVELOPMENT OF A MODEL FOR THE TRAFFIC IN A URBAN INTERSECTION

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Abstract**—**The purpose of this paper is to offer a solution based on the development of a mathematical model in order to optimize traffic lights cycle depending on the timeframe. The model was developed by analyzing and processing data collected from a traffic light intersection of intense traffic in Sibiu, Romania. The model permits the programming of sequences for the fluidization of traffic, through an algorithmic approach.

Optimization of traffic light cycle in an urban intersection, with regard to the timeframe and traffic volume, is necessary, in order to increase traffic management quality so that we have sustainable traffic which leads to time gained for the traffic participants in these intersections. Another important aspect gained by this is the optimization of noise management and decrease of gas emission pollution for these intersections.

Keywords**—**Mathematical model, monitoring, quality of urban traffic, simulation

I. Introduction

IN order to determine a viable model of calculus for traffic lights cycle intersection geometry, traffic volumes and arrival models must be taken into consideration. The capability of individuals arriving in an intersection controlled by traffic lights affects said intersections` capacity. In regard to traffic signal capacity, the main factor that must be take into consideration and traffic control factors and geometrical factor, such as band position and width, gradient/band slope and radius of any return movement.

It is positively necessary for certain intersections to realize, design, implement and use traffic control systems. Depending on the situation that the intersection is in (independent or correlated to a road section which operates under a coordinated system) the implementation of these systems has to be consequently adapted. It is necessary to use traffic light installation in an intersection when disturbances occur (repeated blockages of access roads in intersections; repeated forming of vehicle lines caused by large traffic flow density on the main street which affect secondary traffic crossing or infiltration, pedestrian congestion and extended waiting time, accidents due to failure of intersection priority rules).

The term 'simulation' in broadly speaking, mean any model which attempts to represent or mirror actual traffic behavior and includes equilibrium models.

A mixture of mathematical models and optimization techniques are used to carry out in order to control the traffic. Mathematical models are not only scientific substantiating the quality of the sustainable traffic management in urban intersection, but they have the advantage that they can be simulated by a computer, which contributes to the higher speed of getting the conclusions of the traffic analysis regarding the cycles of the traffic light intersections.

In the specialty literature are well known different models for simulations of traffic aspects, and intelligent transport systems. The main important models used during the last 20 years [1] - [7] are presented on the Table I:

TABLE I
MODELS USED TO SIMULATE TRAFFIC FLOWS

Model	Approach
AIMSUN2	Combined discrete-continuous simulation of the traffic network
ARCADY	Assessment of Roundabout Capacity And DelaY - is used for predicting capacities, queues, delays (both queueing and geometric) and accident risk at roundabouts
CONTRAM	Assigns single vehicles or small groups; releases them sequentially
DRACULA	Driver responses assessed against normal experience
DYNASMART	Simulation of network dynamics, varying information systems
FASTCARS	Simulation of driver responses to traffic information
FREFLO	Event-based microsimulation moving each vehicle intermittently
FRESIM	Stochastic microsimulation of traffic on freeways
INFRAS-FRESIM	Stochastic model (Predict freeway traffic, detection and control of incidents)
INTEGRATION	Integrated simulation and traffic assignment model
KRONOS	Finite difference methods to solve system of partial differential equines
MITRAM	Real-time or batch mode simulation; fuzzy vehicle modules

TABLE I (CONTINUED)
MODELS USED TO SIMULATE TRAFFIC FLOWS

Model	Approach
NEMIS	Simulate route guidance strategies
NETSIM	Interval-based microsimulation; events are updated every second
OSCADY	An advanced traffic signal design program for the rapid optimization of isolated signal controlled intersections.
PARAMICS	Software Traffic Simulation Software - high-performance microsimulation software tools for accurate and dynamic traffic analysis.
PARAMICS	Microsim: vehicle following, gap acceptance and lane changing
SATURN	Combined deterministic user equilibrium and simulation; dynamic; vehicles in platoons;
SCATSIM	Simulates traffic under various conditions (microscopic)
SMARTPATH	Microsimulation For automated highway systems
SYNCHRO	Software tools needed to simulate and optimize traffic before deployment
THOREAU	Macro simulation of speed-flow relations
TRAF-NETSIM	Event drove network simulation Study effects of intersection control devices
TRANSIMS	Microsimulation of metropolitan networks; uses cellular automata
TRANSYT	A traffic modeling software that can be used for designing, modeling and studying everything from individual isolated junctions to large complex networks.
TRANSYT	An off-line deterministic user equilibrium model
VISSIM	A visual block diagram language for simulation of dynamical systems and model- based design of embedded systems.

II. MEASUREMENTS AND DATA ANALYSIS

Electric traffic lights are programmed to function with cyclical data, succeeding one after another in a pre-defined order [8], [9], and [10].

The guidelines provided for drivers by the operating mode of traffic lights for vehicles are as following: red/ yellow-green-yellow-red.

Traffic lights installations have operation phases which are a part of a cycle duration, length of time from the appearance of green until the start of "the green" time.

In general, two distinct periods are included in a phase: the intake of the time period and the time required for clearing the intersection period. To determine the necessary time in seconds, the following relationship can be used:

$$\mathbf{t_i = t_e\text{-}t_a} \qquad (1)$$

Where $-t_a$ is the access time and t_e is the evacuation time. In accordance with the literature [11], they can be determined by (2):

$$\mathbf{T_e = t + \frac{V_e}{a} + T\frac{D_e+l}{V_e}, a = \frac{D_a}{V_a}} \qquad (2)$$

where t is perception-reaction time of the driver, measured in seconds; l – length of the vehicle(m); a – deceleration (m/s^2); D_e – evacuation distance; (m); D_a – remote access(m); V_e – exhaust speed (m/s^2); V_e – access speed (m/s^2).

Also established in the bibliographic material, are the formulas that determine the duty cycle of the traffic lights (the period of time between two successive occurrences of the same indications of electric traffic lights).

Several methods can be used in the programming of traffic lights [12]: Greensbields method (based on the assumption that the arrival of vehicles at an intersection is Poisson); Korte method (a European adaptation of the Greensbields method); Webster method (has the purpose of minimizing the delay time experienced by vehicles); Le Cocq method (analogous to the Webster method); traffic capacity analysis.

The intersection chosen for the study research has main car traffic during peak hours.

As can be observed in previous images (fig. 1 and fig. 2), the monitoring locations are placed in the following positions:

1) ML1,2 (Monitoring Location 1, 2) Vasile Milea – north street;
2) ML3 (Monitoring Location 3) Semaforului – east street;
3) ML4, 5 (Monitoring Location 4, 5) Vasile Milea – south street;
4) ML6 (Monitoring Location 6) Rahovei – west street

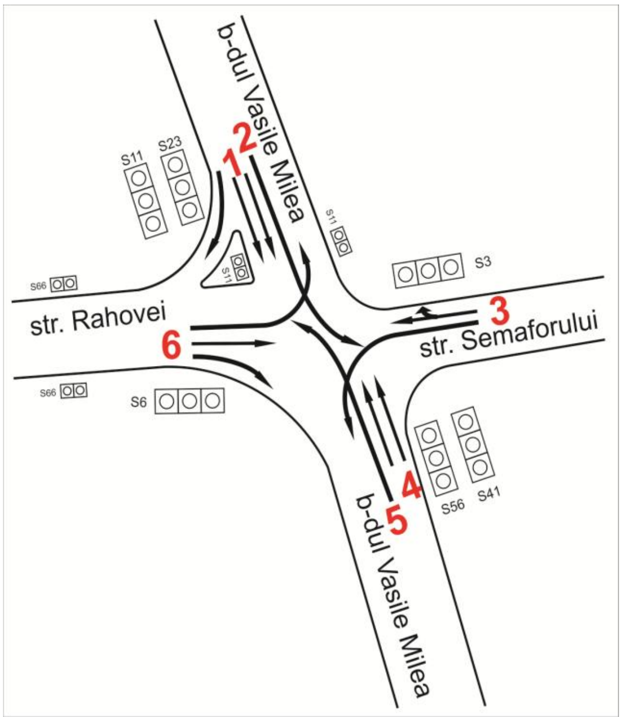

Fig. 1. The monitoring area

During each color of traffic lights placed in the six points of the study was timed. Times are presented in Table II. As we can see the red light varies between 62 and 86 seconds and the green one between 11 and 35 seconds.

TABLE II
TIMING LIGHT OF MONITORING LOCATION

Monitoring Location	Time of red color (seconds)	Time of yellow color (seconds)	Time of green color (seconds)
ML1	62	3	35
ML2	78	3	19
ML3	75	3	22
ML4	72	3	25
ML5	86	3	11
ML6	84	3	13

The states the intersection lights are passing through are presented in Table III.

TABLE III
THE STATES OF THE INTERSECTION LIGHTS

Position	ML1	ML2	ML3	ML4	ML5	ML6
S1	G	R	Y	G	R	Y
S2	Y	G	R	Y	G	R
S3	R	Y	G	R	R	R
S4	G	R	Y	G	R	Y
S5	Y	G	R	Y	G	R
S6	R	R	R	R	Y	G

Fig. 2 A view of the monitored area

III. PROBLEM SOLUTION

In the specialty literature, there are presented more mathematical models of traffic prognosis: operational models, ponderable models, models based on extrapolation, a.s.o.

Light signals of traffic lights, red, yellow, green, can be interpreted as signals r (t), y (t), g (t), which are null for moments of time t<0. Generically, we can mark down x (t) (x (t) as one of the lights red, yellow, green, noted r (t), y (t) or g(t)) [13].

The Laplace transform establishes the correspondence between the time domain and the complex plane. The Laplace transform is an operator through which the original function f (t) corresponds to the image function F(s) and is denoted by L(f(t)) = F(s) or $f(t) \overset{\perp}{\rightarrow} F(s)$. Also, the original functions are denoted by lower case letters f(t), g(t), h(t), ... and their images with the corresponding capital letters F(s), G(s), H(s), ...

Therefore, the sampling period T, expressed in Table I, the sampled signal x * (t) has the form [14]:

$$x^*(t) = \sum_{k=0}^{\infty} x(kT)\delta(t-kT) \qquad (3)$$

Laplace transform [15] for

$$\boldsymbol{\delta\ (t\text{-}kT) = e^{-skT}} \qquad (4)$$

and $e^{sT} = z$

⟹ the expression for the Laplace transform (5) of the sampled signal:

$$\mathbf{X^*(s) = L\{x^*(t)\} = \sum_{k=0}^{\infty} x(kT)e^{-skT} = \sum_{k=0}^{\infty} x(kT)z^{-k}} \qquad (5)$$

The expression from (2) is actually transforming Z of the sampled signal:

$$\mathbf{X(z)= Z\{x^*(t)\}= Z\{x(kT)\}} \qquad (6)$$

Transform Z is linear and has properties that can be applied on signal delays or anticipations.
According to the theorem with a time delay d:
The transform Z sampled signal with period (7) representing a time delay operator T;

$$\mathbf{T = z^{-d}X(z)([\quad]), \qquad z^{-1}} \qquad (7)$$

The transform Z of he expected signal is presented in (8):

$$\mathbf{Z\big(X(k+d)\big) = z^{d}X(z) - \lfloor z^{d}(0) + z^{d-1}x(1) + \cdots + zx(d-1)\rfloor} \qquad (8)$$

The delay and the anticipation theorems will be applicable for the transform Z of the light signals of traffic lights r(t), y(t), g(t). After the determination of the duration d, we can calculate which will cause that red light signal r(t), to be delayed during time intervals when the traffic is not very intense, and to be in advance during the high traffic time intervals.

Therefore, ML1, ML2, ML3, ML4, ML5, ML6 in Table I, for Ti defined in (1) and for any natural number k, the mathematical model of optimized light signal [13] is presented in (9):

$$\mathbf{x_{optim}(t)=(x_{optim}^{ML1}(t),x_{optim}^{ML2}(t),x_{optim}^{ML3}(t),x_{optim}^{ML4}(t),x_{optim}^{ML5}(t),x_{optim}^{ML6}(t))} \qquad (9)$$

where:

$\mathbf{x_{optim}^{MLi}(t)}$ are presented in (10) - (15)

$$\mathbf{x}_{\mathbf{optim}}^{\mathbf{ML1}}(\mathbf{t}) = \begin{cases} \mathbf{r}(\mathbf{t}) & \mathbf{t} \in [\mathbf{100k}, \mathbf{62} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{y}(\mathbf{t}) & \mathbf{t} \in [\mathbf{62} - \mathbf{d} + \mathbf{100k}, \mathbf{65} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{g}(\mathbf{t}) & \mathbf{t} \in [\mathbf{65} - \mathbf{d} + \mathbf{100k}, \mathbf{35} + \mathbf{d} + \mathbf{100k}] \end{cases} \quad (10)$$

$$\mathbf{x}_{\mathbf{optim}}^{\mathbf{ML2}}(\mathbf{t}) = \begin{cases} \mathbf{r}(\mathbf{t}) & \mathbf{t} \in [\mathbf{100k}, \mathbf{78} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{y}(\mathbf{t}) & \mathbf{t} \in [\mathbf{78} - \mathbf{d} + \mathbf{100k}, \mathbf{81} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{g}(\mathbf{t}) & \mathbf{t} \in [\mathbf{81} - \mathbf{d} + \mathbf{100k}, \mathbf{19} + \mathbf{d} + \mathbf{100k}] \end{cases} \quad (11)$$

$$\mathbf{x}_{\mathbf{optim}}^{\mathbf{ML3}}(\mathbf{t}) = \begin{cases} \mathbf{r}(\mathbf{t}) & \mathbf{t} \in [\mathbf{100k}, \mathbf{75} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{y}(\mathbf{t}) & \mathbf{t} \in [\mathbf{75} - \mathbf{d} + \mathbf{100k}, \mathbf{78} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{g}(\mathbf{t}) & \mathbf{t} \in [\mathbf{78} - \mathbf{d} + \mathbf{100k}, \mathbf{22} + \mathbf{d} + \mathbf{100k}] \end{cases} \quad (12)$$

$$\mathbf{x}_{\mathbf{optim}}^{\mathbf{ML4}}(\mathbf{t}) = \begin{cases} \mathbf{r}(\mathbf{t}) & \mathbf{t} \in [\mathbf{100k}, \mathbf{72} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{y}(\mathbf{t}) & \mathbf{t} \in [\mathbf{72} - \mathbf{d} + \mathbf{100k}, \mathbf{75} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{g}(\mathbf{t}) & \mathbf{t} \in [\mathbf{75} - \mathbf{d} + \mathbf{100k}, \mathbf{25} + \mathbf{d} + \mathbf{100k}] \end{cases} \quad (13)$$

$$\mathbf{x}_{\mathbf{optim}}^{\mathbf{ML5}}(\mathbf{t}) = \begin{cases} \mathbf{r}(\mathbf{t}) & \mathbf{t} \in [\mathbf{100k}, \mathbf{86} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{y}(\mathbf{t}) & \mathbf{t} \in [\mathbf{86} - \mathbf{d} + \mathbf{100k}, \mathbf{89} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{g}(\mathbf{t}) & \mathbf{t} \in [\mathbf{89} - \mathbf{d} + \mathbf{100k}, \mathbf{11} + \mathbf{d} + \mathbf{100k}] \end{cases} \quad (14)$$

$$\mathbf{x}_{\mathbf{optim}}^{\mathbf{ML6}}(\mathbf{t}) = \begin{cases} \mathbf{r}(\mathbf{t}) & \mathbf{t} \in [\mathbf{100k}, \mathbf{84} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{y}(\mathbf{t}) & \mathbf{t} \in [\mathbf{84} - \mathbf{d} + \mathbf{100k}, \mathbf{81} - \mathbf{d} + \mathbf{100k}] \\ \mathbf{g}(\mathbf{t}) & \mathbf{t} \in [\mathbf{87} - \mathbf{d} + \mathbf{100k}, \mathbf{13} + \mathbf{d} + \mathbf{100k}] \end{cases} \quad (15)$$

The analytic expression of the functions in the model (9), are allowing them to become arguments of the transform Z, in applying of the delay and anticipation theorem, to optimize the cycle of traffic lights and the scientific substantiation of modeling and simulation of the traffic management quality sustainable in an urban intersection

IV. CONCLUSION

Urban traffic models have been of greatest interest, because congestion adds to the complexity, but traffic modeling is also essential for non-urban road planning and investment. [16] In Sibiu city, the tendency of traffic congestion during the rush hours is not caused by undisciplined road users (motorists and pedestrians), but by achieving maximum carrying traffic capacity of the analyzed arteries, in addition with the reconfiguration. [17] Having in view that the number of passengers on the road is constantly increase and the fact that the roads are increasingly congested, the attention of the specialists will be focused on the intelligent traffic control. Beside them the stakeholders from economy and environment will join into research in order to prevent the traffic jams.

Optimizing traffic light cycle in urban intersections, is depending on the time and implicitly the volume of traffic

In this paper it was presented a mathematic model for optimization the traffic light cycle according to the time frames. In order to ensure a smooth traffic, these formulas can be extended or applied analogously to all traffic lights in the town. The equation (9) can, also, be adapted to any other urban intersection similar to the one presented in this paper. The model can be analyzed and simulated in Matlab, Maple software, for example, or other software [18] because it involves operations with real functions.

All of the above will allow a time gain for all participants to the intersections traffic and a better management of the noise and emissions pollution from these areas.

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