Aspects of modeling and simulation of the traffic management quality sustainable in an urban intersection

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Abstract: - This paper presents a solution on the optimization of traffic lights cycle depending on the timeframe by developing a mathematical model. Based on the analysis and processing of data obtained from a traffic lights intersection with intense traffic in Sibiu, was developed a mathematical model that allows an algorithmic approach to programming sequences for ensuring a smooth traffic. The article also includes a section in which we synthesized examples of useful software in the analysis of urban traffic. The optimizing of the traffic light cycle in urban intersections, depending on the timeframe and implicitly, on the traffic volume, we consider that will increase the quality of traffic management, leading to a sustainable traffic, leading to time gain for those involved in the traffic of such intersections and also to a more efficient management of noise and gas emissions pollution from these intersections.

Key-Words: - Mathematical model, monitoring, quality of urban traffic, simulation, sustainable

1 Introduction

Various models for calculation of cycle traffic lights are considering the intersection geometry, traffic volumes and arrivals model. The capacity of an intersection where traffic is controlled by traffic lights is affected by the capabilities of individual arrivals in the intersection. The main factors that are affecting the capacity of a traffic signal are, traffic control factors and the geometrical factors (band position, band width, gradient/band slope and radius of any return movement).

Conception, design, implementation and use of traffic control systems are absolutely necessary in certain intersections. Implementation of these systems depends on the situation that the intersection is in - is independent or correlated to a road section, which operates under coordinated system [2].

The use of traffic light installation in a street intersection is necessary when the normal circulation of vehicles is disturbed by: repeated blocking traffic on access roads in intersections; repeated formation of lines of vehicles when the density of traffic flows on the main street is too large to allow a secondary traffic crossing or infiltration, pedestrian congestion and extended waiting, accidents due to failure intersection priority rules.

Functioning of electric traffic lights have a cyclical data supplied succeeding one after another in a defined order [3], [6].

The operating mode of traffic lights for vehicles provides to the drivers, the following guidelines [4,6]: red/ yellow-green-yellow-red.
The phases of operation of a traffic lights installations is a part of a cycle duration, duration of time from the start of the green until the start of “the green” time [15], [16].

A phase generally comprises two distinct periods: the period of intake time and the necessary period of time for clearing the intersection. In seconds, the necessary time can be determined by the relationship:

$$T_i = T_e - T_a$$  \hspace{1cm} (1)

where $T_e$ is evacuation time, and $T_a$ access time.

According to the specialty literature [14], they are calculated according to the formula:

$$T_e = t + \frac{V_e}{a} + \frac{D_e + l}{V_e}, \quad a = \frac{D_e}{V_e}$$ \hspace{1cm} (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$^2$); $V_{ac}$ – access speed (m/s$^2$).

For the duty cycle of the traffic lights, which means the time between two successive occurrences of the same indications of electric traffic light, are also established formulas in bibliographic materials[14].

There are several methods used to programs running traffic lights [5,14], as: Greenshields method(using the assumption that the arrival of vehicles at an intersection is Poisson); Korte method( an adaptation for the European method Greenshields) Webster method(aims to minimize delays experienced by vehicles); Le Cocq method (is a method analogous to Webste); traffic capacity analysis (analysis of the relationship between volume and capacity).

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

- ML1 (Monitoring Location 1) Balea-north street;
- ML2 (Monitoring Location 2) Stefan cel Mare – east street;
- ML3 (Monitoring Location 3) Moldoveanu – south street;
- ML4 (Monitoring Location 4) Stefan cel Mare – west street.

<table>
<thead>
<tr>
<th>Monitoring Location</th>
<th>Time of red colour (seconds)</th>
<th>Time of yellow colour (seconds)</th>
<th>Time of green colour (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML1</td>
<td>75</td>
<td>3</td>
<td>34</td>
</tr>
<tr>
<td>ML2</td>
<td>87</td>
<td>3</td>
<td>22</td>
</tr>
<tr>
<td>ML3</td>
<td>86</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>ML4</td>
<td>87</td>
<td>3</td>
<td>22</td>
</tr>
</tbody>
</table>

The states the intersection lights are passing through, are presented in table 2.

<table>
<thead>
<tr>
<th>State</th>
<th>ML1</th>
<th>ML2</th>
<th>ML3</th>
<th>ML4</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>red</td>
<td>yellow</td>
<td>green</td>
<td>red</td>
</tr>
<tr>
<td>S2</td>
<td>yellow</td>
<td>green</td>
<td>red</td>
<td>yellow</td>
</tr>
<tr>
<td>S3</td>
<td>green</td>
<td>red</td>
<td>yellow</td>
<td>Green</td>
</tr>
<tr>
<td>S4</td>
<td>yellow</td>
<td>green</td>
<td>red</td>
<td>Yellow</td>
</tr>
</tbody>
</table>

Fig. 1. The monitoring area
Fig. A map for the monitored area
3 Problem Solution

In the speciality materials, there are known more mathematical models of traffic prognosis: models based on extrapolation; ponderal models; operational models; models based on preferential balance method [14].

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 \( g(t) \)).

Therefore, the sampling period \( T \), expressed in Table 1, the sampled signal \( x^*(t) \) has the form [1]:

\[
x^*(t) = \sum_{k=0}^{\infty} x(kT) \delta(t - kT)
\]  

(3)

Because the Laplace transform for \( \delta(t-kT) \) is \( e^{-sT} \) and \( e^{-sT} \) is marked with \( z \), we obtain for the Laplace transform of the sampled signal, the expression:

\[
X(z) = Z(x^*(t)) = \sum_{k=0}^{\infty} x(kT) z^{-kT} = \sum_{k=0}^{\infty} x(kT) z^{-k}
\]  

(4)

Expression of formula (2) is actually transform \( Z \) of the sampled signal:

\[
X(z) = Z(x^*(t)) = Z(x(kT))
\]  

(5)

Transform \( Z \) is linear and has properties that can be applied on signal delays or anticipations. According to the theorem with a time delay \( d \) [1]:

- transform \( Z \) sampled signal with period \( T \) is equal to \( z^dX(z) \) ([1]), \( z^d \) representing a time delay operator \( T \);
- transform \( Z \) of the expected signal is,

\[
Z\left(x(kT + d)\right) = z^dX(z) - \left[z^d x(0) + z^{d-1} x(1) + \ldots + z x(d-1)\right]
\]  

(6)

Obviously, for the transform \( Z \) of the light signals of traffic lights \( r(t), y(t), g(t) \), the delay and anticipation theorems will be applicable, so the duration \( d \) to be determined, 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 in tabel 1, for \( T_i \) defined in formula (1), \( d \in (0,T_i) \) and for any natural number \( k \), the mathematical model of optimized light signal is:

\[
x_{\text{optim}}(t) = (x_{\text{ML1}}^\text{optim}(t), x_{\text{ML2}}^\text{optim}(t), x_{\text{ML3}}^\text{optim}(t), x_{\text{ML4}}^\text{optim}(t))
\]  

(7)

where,

\[
x_{\text{ML1}}^\text{optim}(t) = \left\{ \begin{array}{ll}
r(t), & t \in [112k, 75 - d + 112k] \\
y(t), & t \in (75 - d + 112k, 78 - d + 112k] \\
g(t), & t \in (78 - d + 112k, 34 + d + 112k]
\end{array} \right.
\]

\[
x_{\text{ML2}}^\text{optim}(t) = \left\{ \begin{array}{ll}
r(t), & t \in [112k, 87 - d + 112k] \\
y(t), & t \in (87 - d + 112k, 90 - d + 112k] \\
g(t), & t \in (90 - d + 112k, 22 + d + 112k]
\end{array} \right.
\]

\[
x_{\text{ML3}}^\text{optim}(t) = \left\{ \begin{array}{ll}
r(t), & t \in [112k, 86 - d + 112k] \\
y(t), & t \in (86 - d + 112k, 90 - d + 112k] \\
g(t), & t \in (90 - d + 112k, 23 + d + 112k]
\end{array} \right.
\]

\[
x_{\text{ML4}}^\text{optim}(t) = \left\{ \begin{array}{ll}
r(t), & t \in [112k, 87 - d + 112k] \\
y(t), & t \in (87 - d + 112k, 90 - d + 112k] \\
g(t), & t \in (90 - d + 112k, 22 + d + 112k]
\end{array} \right.
\]

The analytic expression of the functions in the model (7), 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.

4 Simulations on specific software for traffic forecast

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 speciality materials are well known different software for simulations on traffic aspects, and intelligent transport systems, as ARCADY (fig.3), OSCADY (fig.4), TRANSYT (fig.5), SYNCHRO (fig.6), PARAMICS (fig.7), SimTraffic (fig.8), VISSIM (fig.9).

![Fig.3 ARCADY- Intersection geometry and the list of required data](7)
5 Conclusion

Optimizing traffic light cycle according to the timeframes, can be done using mathematical models that can be easily understood by experts in engineering and management, not necessarily by mathematicians. Formulas can be applied analogously to other traffic lights, like the intersection traffic lights in Sibiu, Romania, in order to ensure a smooth traffic. Optimizing traffic light cycle in urban intersections, depending on the time and implicitly the volume of traffic, resulting into an increased traffic quality management, as it leads to a sustainable traffic. 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.

The mathematical formula (7) can be adapted to any other urban intersection analogous to that of Figure 1. It also can be analyzed and simulated in software like Matlab, Maple, because it involves operations with real functions.

The subject of this article will be one of the future research directions of the authors. We are waiting for the opinions of the scientific community about mathematical modeling written in this article.

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