Vehicle streams control on the basis of indistinct logic

PODVALNY SEMEN, BURKOVSKY VIKTOR, BEREZHNOY Konstantin, SEMYNIN SERGEY
Chair of automation and informatics in technical systems
Voronezh Technical State University
394026, Voronezh, 14 Moscow avenue
RUSSIA
http://www.vstu.ru

Abstract: - The drastic increase in the number of vehicles and traffic has aggravates the road situation not only abroad but in this country as well. The traffic jam problem may have various solutions, e.g. by extending the present road network (RN). This solution is, however, a rather long and expensive one. Another way is to manage the existing situation, i.e. to create a system for traffic management based on the RN on hand. This way appears to be of value judging both by cost and time of implementation.

The problem of the traffic flow management may be stated and solved by different methods. The traffic management system on the basis of indistinct logic is implemented after the proposed ideas have been thoroughly tested for efficiency and debugged.

Key-Words: - vehicles, road network, crossroads, stream, the traffic management system, indistinct logic, control system of transport streams.

1 Introduction

In regulation systems of transport streams, based on the use of rigid algorithms of control, coordination of traffic lights operation is calculated beforehand taking into account distances between crossroads, mathematically hypothetical streams intensity and desirable average movement speed. Obvious disadvantage of such an approach to regulation is the absence of the stream intensity change registration along the highway due to driving in and out of cars at crossroads and impossibility to maintain recommended movement speed because of unforeseen circumstances. Hence traffic jams arise inevitably. The use of indistinct control algorithms which change traffic lights switching moments according to S movement current situation can be offered to avoid this disadvantage.

The problem of movement regulation by means of control of traffic lights signals switching is set as the problem of minimization of an average waiting time of cars on their routes (the route is considered to be constants for every car) or as the problem of total waiting time of cars on crossroads. In case of comparing the efficiency of different traffic lights control systems it is necessary to compare total waiting time of cars at crossroads. A heuristic control method, known as a green wave, is used in a control system of transport streams (CSTS) when a transport stream moves without stops in one direction on a red traffic light signal.

2 Problem Formulation

To realize such an approach it is necessary for all the traffic light along the street to have the cycle time

$$t_{cycl} = t_r + t_{gr} + 2t_{yel}$$  (1)

($t_r$ - duration of a red signal burning, $t_{gr}$ - green, $t_{yel}$ - yellow) identical, i.e. traffic lights operation should be synchronous. The time interval between the starting points of traffic lights cycles on two neighboring crossroads is the synchronization time $t_{synhr}$. It is defined by average travel time between two neighboring crossroads. As the distances between crossroads in one street can differ, it is reasonable to have an independent CSTS for each crossroad to adjusts $t_{synhr}$, control proceeding from the situation on two neighboring crossroads, namely from the total average waiting time on crossroads in direct and return directions taking into consideration direct and angular traffic. I.e. The purpose of regulation is minimization by fine tuning of $t_{synhr}$ of sum

$$t_{exp} = t_{exp11} + t_{exp12} + t_{exp21} + t_{exp22}$$  (2)

of an average waiting time of cars, where $t_{exp11}$ - is total waiting time of cars in the stream $\rho_{11}$ in front of the crossroads 2, $t_{exp12}$ - of a stream $\rho_{11}$ in front
of the crossroads 2, \( t_{\exp 21} \) - of a stream \( \rho_{21} \) in front of the crossroads 1, \( t_{\exp 22} \) - of a stream \( \rho_{22} \) in front of the crossroads 1, (see fig.1).

Fig. 1

The change of \( t_{\text{synh}} \) between two traffic lights leads to automatic change \( t_{\text{synh}} \) on other traffic lights in this street. Thus, CSTS which minimizes average waiting time in front of the traffic lights along the street is realized on the basis of indistinct logic with certain rule base.

3 Problem Solution

An ideal CSTS should react adequately to any car sequence with any time intervals between them, establishing optimum \( t_{\text{synh}_{\text{opt}}} \). Being put into practice such an approach leads to great computing and structural difficulties. Therefore the following entrance linguistic variables are offered in the suggested CSTS on the basis of indistinct logic: \( n_{11} \) - the number of cars which have passed on green light (in a horizontal direction) during one cycle in \( \rho_{11} \) direction, \( n_{12} \) - the number of cars which have passed on green light during one cycle (in vertical direction when red lights burns in horizontal direction) in direction \( \rho_{12} \), \( n_{21} \) - the number of cars which have passed on green light during one cycle (in a horizontal direction) in \( \rho_{21} \) direction, \( n_{22} \) - the number of cars which have passed on green light (in a vertical direction while red light burns in horizontal direction) in \( \rho_{22} \) direction, \( t_{\text{synh}} \) - current synchronization time and a target linguistic variable \( \Delta t_{\text{synh}} \) - the change of synchronization time \( t_{\text{synh}} \).

In practice, however, vehicles more in accordance with following constant distribution law - the main stream of cars with the uniform distribution law which has collected in front of the traffic light during the time when a red light was burning passes first with the minimum time interval between cars \( \Delta t \), and then rare cars pass which do not influence much the distribution law. Therefore for every set of values \( n_{11}, n_{12}, n_{21}, n_{22} \) there exist an optimum \( t_{\text{synh}_{\text{opt}}} \) value. The aim of the given system of a conclusion is to put out \( \Delta t_{\text{synh}} \) for every set of values \( n_{11}, n_{12}, n_{21}, n_{22} \), \( t_{\text{synh}} \) which changes \( t_{\text{synh}_{\text{opt}}} \) in the direction of the optimum \( t_{\text{synh}_{\text{opt}}} \) value. The output is carried out in two stages. Firstly, the system for the given set of values \( n_{11}, n_{12}, n_{21}, n_{22} \) (by approximation) puts out \( t_{\text{synh}_{\text{opt}}} \) value for which \( t_{\exp} \) value is minimum and then \( \Delta t_{\text{synh}} \) is calculated on the received \( t_{\text{synh}_{\text{opt}}} \) and current \( t_{\text{synh}} \). The total numbers of base rules will make \( N_{11} N_{12} N_{21} N_{22} \), where \( N_{ij} \) - is the number of values of \( n_{ij} \) quantity. \( i = \lfloor \frac{1}{2} \rfloor, \ j = \lfloor \frac{1}{2} \rfloor \).

Modeling of vehicle movement through two crossroads with the aim of differing minimum \( t_{\exp} \) is carried out for creating such a rule base (system training). The rule base is filled as follows. The \( t_{\text{synh}_{\text{opt}}} \) value under which \( t_{\exp} \) has the minimum is defined by means of computer vehicle movement model for preset \( n_{11}, n_{12}, n_{21}, n_{22} \) values. Then it is defined at which \( \Delta t_{\text{synh}} \) - negative and positive - new value

\[
  t_{\text{synh}_{ij}} + 1 = t_{\text{synh}_{ij}} + \Delta t_{\text{synh}}, \quad (3)
\]

will be closer to optimum \( t_{\text{synh}_{\text{opt}}} \) (at \( t_{\text{synh}_{ij}} + 1 + \Delta t_{\text{synh}} > t_{\text{cycl}} \) is accepted

\[
  t_{\text{synh}_{ij}} + 1 = t_{\text{synh}_{ij}} + \Delta t_{\text{synh}} + t_{\text{cycl}}, \quad (4)
\]

and at \( t_{\text{synh}_{ij}} + 1 + \Delta t_{\text{synh}} < 0 \) is accepted

\[
  t_{\text{synh}_{ij}} + 1 = t_{\text{cycl}} - t_{\text{synh}_{ij}} + \Delta t_{\text{synh}} \quad (5)
\].

The vehicle movement model, performing \( n_{11}, n_{12}, n_{21}, n_{22} \rightarrow t_{\exp} \) function is used for realization of such method of filling the rule base [2,3].

The model of analysis of traffic light regulation variants is used. This model is intended for analysis and selection of traffic light regulation minimizing the time of transport objects stay in the system.

The model includes the system of \( k1, k2 \ldots \)
k15 ... crossroads connected with each other awe divided by S1, S2 ... S14 ... sections of certain length. Every crossroads has its traffic light with the time of red forbidding signal $t_{red(k)}$ and the time of green permitting signal $t_{gr(k)}$. The cycle time is defined by the sum of

$$T_c(k) = t_{red(k)} + t_{gr(k)}. \quad (6)$$

Time distribution of red and green signals in the cycle, the cycle length as well as the phases shift are defined by the chosen regulation algorithm and modeling time.

At the initial moment the time of a transport object stay in the system $t_{st}=0$. At the approaching to the crossroads k1 the time is calculated according to the formula

$$t_{st}=t_{st}+t_{st(s1)}, \quad (7)$$

where $t_{st(s1)}$ - is the passing time of s1,

$$t_{st(s1)}= \frac{v_{avg(s1)}}{s1}. \quad (8)$$

If where is a green light signal on the crossroads then the time is calculated according to the formula

$$t_{st}=t_{st}+t_{st(k1)}, \quad (9)$$

$t_{st(k1)}$ – is the time of passing through the crossroads k1 and it equal

$$t_{st(k1)}= \frac{v_{avg(s1)}}{k1}. \quad (10)$$

The movement continues with the average speed $v_{avg(s2)}$ which is defined by the conditions in section s2, namely by stream intensity $N(s2)$ and density of $q(s2)$, that define dispersal acceleration $a_p$ and braking acceleration $abr$ in it.

$$v_{avg(s)} = f(N(s), q(s)) \quad (11)$$

When there is a red signal on the crossroads braking and a stop takes time:

$$t_{stop(s1)}=v_{avg(s1)}/2abr(s1) \quad (12)$$

$$t_{st}=t_{st}+t_{stop(s1)} \quad (13)$$

After switching on a green signal

$$t_{st}=t_{st}+t_{del(k1)}, \quad (14)$$

t_{del(k1)} - the time of delay at a crossroads k1 on red light, dispersal begins,

$$t_{disp(s1)}=v_{disp(s1)}/2adisp(s1) . \quad (15)$$

If $t_{disp(s1)} < t_{gr(k1)}$ then the movement continues along the next section and

$$t_{st}=t_{st}+t_{disp(s1)} \quad (16)$$

if $t_{disp(s1)} > t_{gr(k1)}$ then the time of passing

$$t_{st}=t_{st}+t_{gr(k1)} \quad (17)$$

and car waits for the next green signal.

The stream speed $v_s$ is defined by connection of stream intensity $N(t,s)$ with its density $q(t,s)$:

$$v_s = \frac{dN}{dq} \quad (18)$$

The movement speed $v$, in its turn, depends greatly on density $q$, i.e.

$$v(s,t) = v[q(s,t)]. \quad (19)$$

Taking into account the continuity condition

$$\frac{\partial q(s,t)}{\partial t} + \frac{\partial N(s,t)}{\partial s} = 0, \quad (20)$$

the general type of connection is established

$$\frac{\partial v}{\partial t} = -v'[v + qv'] \frac{\partial q}{\partial s} + v \frac{\partial q}{\partial s}, \quad v = -q(v')^2 \frac{\partial q}{\partial s}, \quad (21)$$

Where

$$v' = \frac{\partial v}{\partial q} = c \cdot q^{(n-1)/2}, \quad (22)$$

here C is a non-negative constant.

At $n \neq 1$ $x = \frac{v}{v_{max}} = 1 - z^k = 1 - \left(\frac{q}{q_{max}}\right)^k = F(z)$, \quad (23)

where $x$ – is a fixed stream speed; $z$ is fixed stream density

$$z = \frac{q}{q_{max}}; \quad (24)$$

$k$ – is a model parameter describing the degree of stream compressibility

$$k = \frac{n+1}{2}, \quad (25)$$

$$v_{max} = c \cdot q_{max}^k. \quad (26)$$

The above-mentioned parities allow to connect fixed speed $x$, fixed density $z$ and fixed intensity $A = N / N_{max}$ together.

$$x(z) = 1 - z^k; z(x) = (1 - x)^n, A(x) = R^{-1}(A) \quad (27)$$

$$A(x) = R(x) = x \cdot (1 - x)^n \quad (28)$$

$$A(z) = z \cdot (1 - z^k) \quad (29)$$

Graphic dependences of stream speed and its density necessary for calculating movement parameters are shown in Figure 2 and 3[1].

![Fig. 2](image-url)
4 Conclusion

The developed automated system of vehicle movement control shows the efficiency of the new algorithms use for vehicle streams control. Conducted research proved that the advantage of an indistinct logic based system in comparison to rigid non-adaptive control makes 10-15%.

The given control system allows to increase the vehicles stream due to redistribution of green and red traffic light signals optimally taking into account the situation on the crossroads and in all the highway system. Other parameters such as average movement speed increase as well. Transport average idle time on crossroads, vehicles lengths on crossroads and others parameter values decrease. Ecological situation will also improve with the introduction of the system because the vehicle stay time on the crossroads will be reduced and the quantity of fumes will also become less.

However, the proposed system cannot solve all the problems of transport control.

In reality, the throughput of crossroads has low value due to the following reasons:
- non-adherence to traffic rules;
- road accidents;
- bad road and weather conditions;
- continuous increase of movement intensity;
- failure of traffic lights;
- absence of the branched out highway system.

A lot of the listed above parameters tend to constant increase. The above mentioned negative factors were taken into account for reflection of real life situation when modeling the control system the list of literature.

References: