Computers in Railways VII, C.A. Brebbia J.Allan, R.J. Hill, G. Sciutto & S. Sone (Editors)

System for tramway priority at traffic lights

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Abstract

During recent years a debate on a more sustainable transport in Catalunya, and especially in the Barcelona Region, has taken place, resulting in a concentration on more public transport investments.

Within this change in attention to different kinds of mobility, the tramway has gained new force and a tender for construction and exploitation of a new tramline of 17 km has been published. The proposals for this from different constructors were presented to the Barcelona Transport Authority at the beginning of this year.

For this tramway, and for others in the planning phase, INTRA has developed a traffic control strategy for a light signal control which give a maximum of priority of progress to the tramway, and so a maximum commercial speed, with a minimum of loss of capacity for the vehicular traffic.

The priority system is based on the following concepts:

-The traffic light co-ordination should be adapted to two-way tramway driving.

-This base objective will define a minimum green phase for the tram.

-The green wave for the tramway has priority over that of the cars, and includes the time for tram at stops.

-The cycle length and the frequency must be adapted to an hour so that the tram can pass at the same minute each hour. This mean that cycle length of 60", 75" and 90" will be most useful.

-The system, through a by near continuos detection of where the convoys are, functions in different levels of decision: Extensions of green, adjustment of the green phase in time, previous pedestrian demand etc.

-Most traffic lights (four-leg intersections and Roundabouts) will be defined in a two-phase scheme.

The paper presents the basic algorithm for the tramway priority at traffic lights.

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1 Objective

This paper aims to define a system of traffic light regulation which allows trams to move along a two-way streets at a suitable commercial speed, with regular frequency and a minimum of stops due to the traffic lights.

In order to achieve these objectives, preferential treatment must be guaranteed to the trams whereas the rest of the vehicle traffic must be considered as secondary. This is due to the fact that the stops required for the public transport and the flow of vehicle traffic behave differently. Therefore, the measures which benefit one of these may be unfavourable for the other.

2 Maximum commercial speed

The average maximum speed, also known as the commercial speed, which a tram can travel along an urban route depends on a series of parameters such as characteristics of the road (slope, curves, etc.), number of intersections with traffic lights, number of required stops and time of stop, and characteristics of the trams

Based on a detailed analysis of these parameters, the traffic conditions for each road section can be defined. Some generic limitations are as follows: maximum speed at an open section = 50 km/h (maximum urban travel speed), maximum speed at an intersection = 30 km/h, acceleration and deceleration, between 0.9 and 1.1 m/sec^2.

Following an analysis of all of these circumstances, the travel time can be defined for each section of the route by applying the laws of Physics regarding uniform movement and uniform acceleration.

The time of the required stop is difficult to quantify since it depends on several different variables which are difficult to foresee, such as number of users (boarding + disembarking), speed in boarding/disembarking (ticket system), level of occupancy of the tram, environmental conditions...

Therefore, in the sections where there are no required stops the time can be calculated quite accurately. In the sections where there are stops, the time will include an exact component (laws of Physics) and a partially subjective component (required stop).

The maximum commercial speed of the route can be determined based on the quotient of the length of the route and the sum of the time in the different sections. In order to achieve this maximum speed, the movement of the tram must not be interrupted and the traffic lights must be green when it reaches the intersection.

3 Green wave

The concept of green wave is already classic in the traffic regulation. It is probably most popular among car drivers, since all drivers aspire to being able to drive without stopping. The significant public investments in motorways,

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highways, urban ring roads, etc. aim to achieve several objectives, including the green wave, that is, being able to travel without stopping.

3.1 Applications for traffic

In the regulation of traffic lights along a route, a green wave is considered to be the progressive activation of the green traffic lights as a vehicle moves along a road. Besides the moment in which the light turns greens, the length of the passing light or the green light is also important. The greater this time, the more vehicles can enjoy the green wave. The maximum time is equivalent to the minimum time of the green light between all of the intersections along the route.

These concepts are quite simple when they refer to one-way roads. However, when the objective is to synchronise (green wave) a two-way road the subject is more complex, as the lights can not be progressively activated at the same time in both directions. Therefore, this implies a considerable decrease in the passing light. When this decrease is significant, the green wave is interrupted, and the beginning of a new green wave is planned as of this point. Other options might be to favour one direction at certain times and the opposite direction at other times. The subject is even more complicated when it involves synchronisation of a network. There is a vast bibliography on this subject, which can optimise the operation of traffic lights in a network by using the appropriate algorithms.

3.2 Applications for trams

The objective of the green wave for trams is the same as that for cars, which is none other than determining the time at which the traffic lights are activated so that the trams do not have to stop at the intersections. The major difference in comparison to other vehicle traffic is that there is only one tram in each direction during a specific interval of time, which must be a multiple of the cycle.

The concept of cycle is related to the repetitive or cyclic nature of all traffic light regulation. The cycle is defined as the time required for all movements to occur in an intersection. The green wave represents a link between the intersections. In order to ensure a regular link over time, the cycle must be the same in all of the intersections.

In defining the green wave for trams, the methodology used must be different from that employed for private vehicles. As an assumption, only one tram can pass in each cycle and direction. Moreover, in some cycles perhaps none will pass.

To define the green wave of the tram, we will begin by calculating the times of activation of the green lights in one direction of the route. At the moment we will not consider the opposite direction. The moment when the traffic lights are activated will be based on the following formula:

$$Ti(1) = Ti_{-1} + ti_{-1} + ti_{-1}i + Tp \qquad (I)$$

In which:

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Ti(1) moment when the traffic lights are activated in intersection i in direction (1)
Ti_{-1} moment when the traffic lights are activated in intersection i_{-1} in direction (1)
ti_{-1} time to cross intersection i_{-1}
ti_{-1},i time to travel between intersections i_{-1} and i
Tp time of required tram stop

For the opposite direction (2) the moments when the traffic lights are activated will be based on the following formula:

$$Ti(2) = Ti_{+1} + ti_{+1} + ti,i_{-1} + Tp \qquad \text{(II)}$$

In which:
Ti(2) moment when the traffic lights are activated in intersection i in direction (2)
Ti_{+1} moment when the traffic lights are activated in intersection i_{+1} in direction (2)
ti_{+1} time to cross intersection i_{+1}
ti,i_{+1} time to travel between intersection i and intersection i_{+1}
Tp time of required tram stop

In order to calculate the values of Ti(1) and Ti(2) according to formulas (I) and (II) the values for the first intersection in each direction must be defined previously, that is, the Ti (1) and the Ti (2), assuming that there are n-intersections along the route.

Ti (1) and Ti (2) are normally not the same. The difference between these values is referred to as the variable difference Di. This is calculated based on the following formula:

$$Di = Ti(1) - Ti(2) \qquad \text{(III)}$$

In which:
Ti(1) moment when the traffic lights are activated in intersection i in direction (1)
Ti(2) moment when the traffic lights are activated in intersection i in direction (2)

The Di is the minimum separation. Therefore, its maximum value will never be greater than half of the cycle. If it is < 0, we will use the absolute value. If it is greater than half the cycle, we will use the complementary value of the cycle.

Di represents the minimum time during which the traffic lights in the intersection must remain green so that both trams can pass, that is, the tram which moves in direction (1) as well as the tram in the opposite direction [direction (2)]. Di includes moment Ti(1) as well as moment Ti(2).

In order to have the maximum freedom in traffic light regulation of course the variable difference should be as small as possible. The criteria of optimisation must be defined so that the best possible regulation will be achieved, which takes into account the needs of the tram as well as those of other vehicle traffic.

Perhaps the most intuitive criteria for achieving this is as follows. First, calculate the Ti for one direction starting, for example, at Ti (1) = 0. Then, attempt to calculate the same parameter for different moments of the opposite direction, Ti (2). This could be based on every five seconds (0, 5, 10, 15, 20, ... 80, 85), for example. Based on these calculations, 15 series of Di can be defined (for a cycle of 90 seconds). Calculate the following values for each series: MDi, maximum difference, mDi, minimum difference and M-m, difference between the maximum and the minimum.

The series that has the minimum M-m is considered as optimum. For example, if this occur with series 6 it would mean that Ti (1) = 0 and Ti (2) = 25. If the minimum value is recorded in series 14, then it would mean that Ti (1) = 0 and Ti (2) = 80.

Another criteria for choosing the most appropriate series could be based on a specific objective. For example, one might consider an intersection with a very limited amount of green time (3 phases). Then, the 15 series must be analysed to see which has a Di equivalent to or less than the pre-established value in this intersection. From this, the series with the minimum M-m will be chosen.

Assuming that one has already chosen the appropriate series based on a specific criteria and the values of Ti (1) = 0 and Ti (2) = function of the chosen series. This means that some Di have been established and, as a result, some Ti (1) and Ti (2). In order to determine the beginning and end of the green light, the following inequalities must be taken into account:

$$\text{If } Ti(2) - Ti(1) <= C/2 \rightarrow \text{Beginning } Ti(1) \quad \text{End } Ti(2)$$
$$\text{If } Ti(2) - Ti(1) > C/2 \rightarrow \text{Beginning } Ti(2) \quad \text{End } Ti(1)$$

Given the length of the trams and the width of the intersections an additional safety time must be taken into account. This value must be added at the end of the green light in order to ensure that the tram has been able to cross the entire intersection as well as the pedestrian crossing usually located after the intersection.

The sum of the safety time and that of the Di for each intersection provides us with a new time which is referred to as TRAM PASSING BAND (BPT). This will be defined as the minimum time during which the traffic lights that regulate the intersection must be green so that the tram (both directions) can cross the intersection without having to stop. Each intersection will have the following:

Ti	moment when green light is activated in both directions of intersection i.
BPTi	period of time the green light remains activated in intersection i or TRAM PASSING BAND

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4 Compatibility analysis

In the previous section, a methodology was defined to determine the Green Wave of the traffic lights for trams travelling on a two-way road. The Green Wave is defined by two data for each intersection: moment when the green light is activated for the tram (Ti) and minimum period of time the green light remains activated or TRAM PASSING BAND (BPTi).

Traditionally, the regulation of traffic lights for cars is also defined by two parameters for each intersection: moment when the green light is activated (represented by Ii) and period of time green light remains activated, or passing band (represented by Ai).

Within the cycle we have defined two green segments for each intersection. One responds to the need for the passage of the tram (BPTi) and the other to the needs of the other vehicle traffic (Ai). These two segments may have an intersection which leads to different degrees of concurrence: a) None b) Partial or c) Total.

In order to achieve the greatest possible concurrence between these segments, an iterative method must be used, causing one of the series to move in relation to the other, measuring the concurrence. The iteration which leads to the highest concurrence will be that which is considered optimum.

Of course this will also be optimum for the tram, since it allows the tram to travel along the route without stopping. At the same time, it could also concur as much as possible with the regulation for the vehicle traffic. The latter will have to be modified in those intersections where there is no concurrence or only partial concurrence. This is achieved by advancing or delaying the moment Ii when the traffic lights are activated.

When the BPTi > Ai, there can not be full concurrence. There are two possible forms of overcoming this. If possible, increase the Ai. If this is not possible, go to the Di series and identify another series which fulfils the criteria, as mentioned previously, for the intersections with three phases.

5 Cycles and frequencies

The system of the traffic lights regulation and the tramway progression on a prefixed march affects the freedom of the operator to choose the frequency of the tramway.

The user prefers that the tramway always arrives at the same hourly minute to the stop. For frequencies bigger than 8-10 minutes, the regular time is more than a necessity.

First of all, the interval between trams has to be divisor of the 60 minutes of the hour. In a second place, the frequency has to be multiple of the cycle. Finally, if you divide the line of the tramway in ramifications, each of them also has to accomplish the requirements mentioned. For example, In case of two ramifications only the combinations of the cycle length and the frequency indicated in the graphic above are possible. These combinations are based on the hypothesis that half of the trams uses each ramification. There can be also found some few combinations with different branch division.

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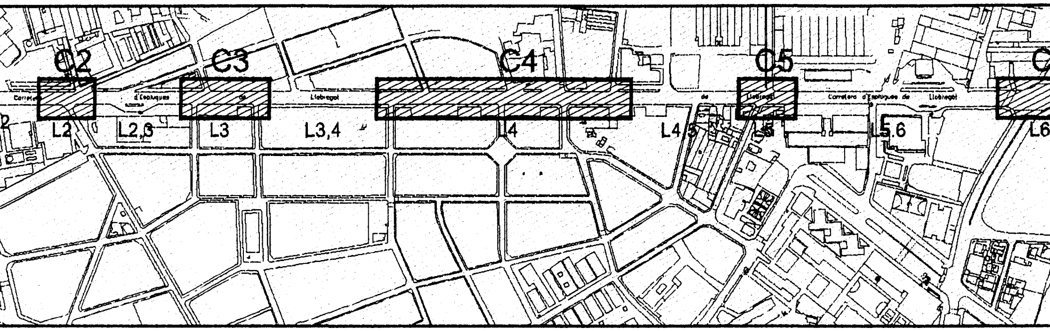
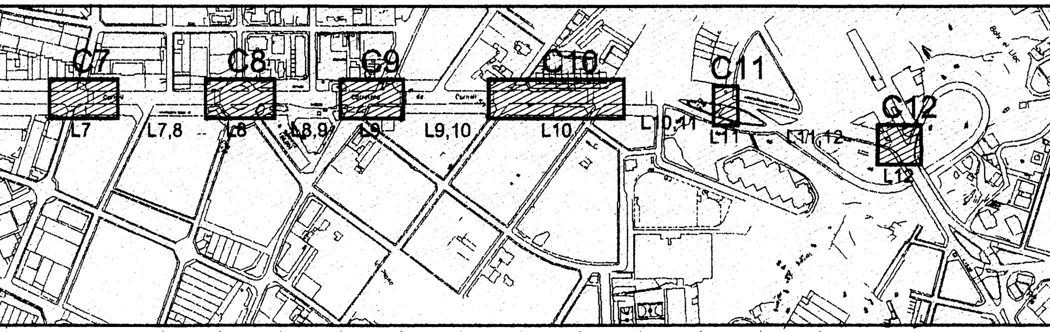
1. LOCALIZATION OF 11 GROUPS OF INTERSECTIONS FOR TRAFFIC LIGHTS COORDINATION



metres	40	253	60	85	120	150	280	130	50	240	95	255
Section	L1	L1,2	L2	L2,3	L3	L3,4	L4	L4,5	L5	L5,6	L6	L6,7



metres	255	95	85	65	95	65	85	155	105	25	345	
Section	L6,7	L7	L7,8	L8	L8,9	L9	L9,10	L10	L10,11	L11	L11,12	L12

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FIG 2. GREEN WAVE FOR TRAMWAY IN TWO DIRECTION AND INCLUDING STOP TIME. (90 SEC CYCLE TIME)

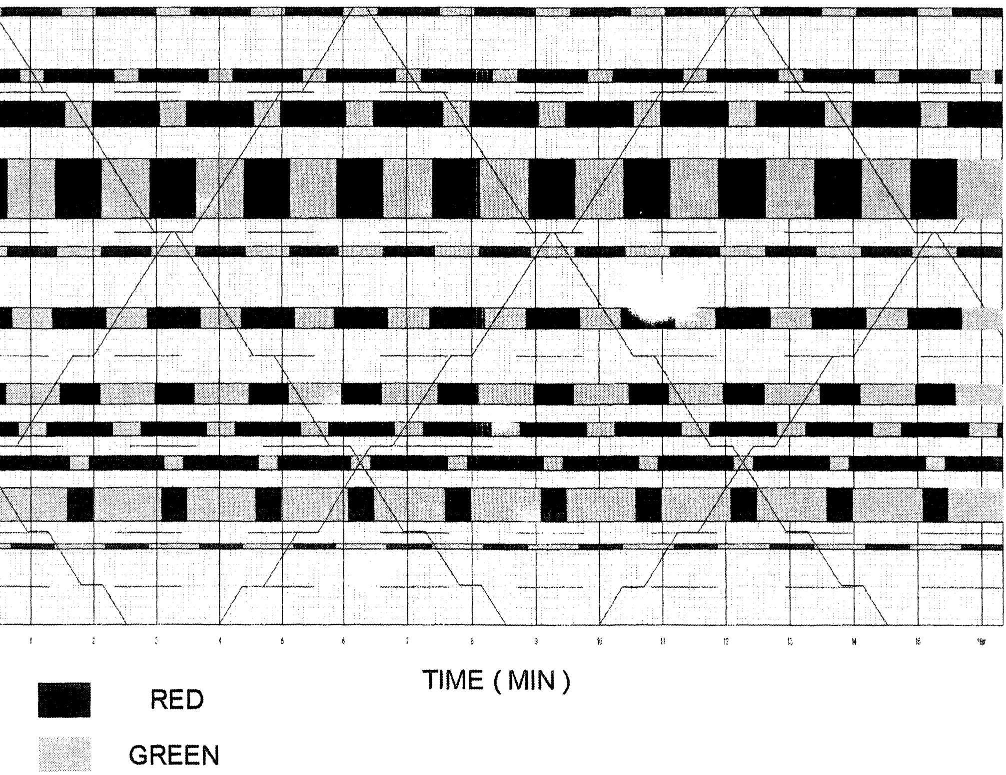

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Table 1. Cycles and frequencies

BASIC CYCLES	Frequency of the tramway *		
	Common branch	1st branch	2nd branch
60”	1	2	4
75”	2.5	5	10
60-90”	3	6	12
75”	3.75	7.5	15
60-100”	5	10	20
75-90”	7.5	15	30
* With the 50% of the tramway on each branch			

6 Conclusions

Traffic light regulations can be developed to obtain a Green Wave for a tram moving along a two-way route.

The regulation with minor effect to the existing regulation can be obtained by a process which optimises the concurrence between both flows of traffic.

The system has the rigidity which characterises traffic light regulations. Therefore, it must be ensured that the tram tracks are always free and there is no build-up of queues of vehicles at the intersections. This is the necessary condition for the trams to adapt the Green Wave.

An increase in the time planned in the required stop represents a loss of the Green Wave.

The loss of the Green Wave by the tram is a significant difficulty in view of achieving a satisfactory regularity in passage, since another Green Wave can not be obtained until the next cycle (usually 75 or 90 seconds).

For minor delays, the traffic light system should be flexible enough so that they can accept the pass of the tram. This flexibility is essential to achieve satisfactory management of the tram.