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EFFECT OF PHASE SEQUENCE IN CAPACITY IN SIGNALIZED INTERSECTIONS

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ABSTRACT

Urban traffic networks are highly governed by intersection capacity. The lack of surface space for roads in cities and the continuously increasing traffic demand, both are challenging traffic engineers towards all type of improvements in traffic management to make existing infrastructure more efficient. Inspired from observations in an intersection in Bogotá, Colombia, it was considered that changing the order of phases within a four-phase (split phased) cycle could have a potential reduction in intergreen times, which means less transition times, and thus an increase in effective green time. Larger green times for a given cycle time represent more cars capable to use the intersection for a given period of time. All the analysis is based on German guidelines for signalized intersections (RiLSA), which permits detailed calculations of intergreen times (unlike HCM and FHA guidelines). In this paper we present and compare the intergreen time calculations from German and US guidelines. In order to evaluate the potential capacity improvements, we designed an experiment that was run using micro-simulation (specifically PTV-VISSIM) to prove the increase in capacity due to phase ordering in this type of intersections. We aimed to isolate the pure maximum capacity increase of the phase changes, therefore uniform traffic composition, saturation flow, and other assumptions were made. Results suggest an increase in discharge flow per access of near 5% per second of effective green time gained due to the measure. In the frame of sustainable transport reduction in delays and stops, besides reduction in travel times, represent potential reduction on emissions and eventually reduction of exposure.

Keywords: Signalized intersection, phase sequence, phase order, intersection capacity, German Traffic Guidelines (RiLSA), Highway Capacity Manual (HCM)

INTRODUCTION

Traffic systems in urban areas are strongly governed by signalized intersections. Urban transportation networks have capacity constraints, given by physical or management reasons (Ferrari, 1997). In urban roads, in addition to the number of lanes, traffic signal lights limit the capacity of urban corridors. These types of controllers are suitable for intersections where other types such as priority rules or roundabouts are not feasible or appropriate. The mean issue related with signalized intersections design is how to distribute the time among the approaching conflicting flows to the intersection. This management implies a certain amount of lost time that is required to permit safety transitions between flows (intergreen times).

According to Beauchamp-Baez et al. (Beauchamp-Baez, Rodriguez-Morales, & Muniz-Marrero, 1997)"poorly designed traffic signals contribute to increase delay, disobedience to the signal indication, accidents, fuel consumption, and pollution among others". In the short run, the most effective action against congestion seems to be a selective construction of new roads, option that is often not feasible due to space or budgetary constraints (De Schutter, 2001). However, under the principles of sustainable transportation, a more efficient use of the existing infrastructure (technology or management) is more desirable. A more efficient traffic system means, for instance, making more cars capable to cross the same intersection, to reduce delays, or to reduce the number of stops.

This paper first summarizes the German and North American approaches for solving the transition times in traffic lights. Secondly, we prove analytically that by using the German guidelines, the order of phases for a four phase (split phased) cycle leads to lower intergreen times. Finally, we designed an experiment aiming to isolate the effect of phase sequence, to quantify the capacity increase (i.e. number of users of the intersection per hour). Results are focused as well on the benefits related with these gains in green time (delay reductions and increase in environmental performance).

BACKGROUND

Studying the effect of the number and the order of phases in signalized intersections has been a topic of interests of scholars for several decades. Already in 1982 G. Jakob highlighted difficulties when finding relationships between intergreen times and capacity, but suggested that there might be a relationship (under the logic that extra green time can be used by vehicles to cross the stop line and, hence, increases the capacity) and acknowledged that further research would be needed. Krüger (1985) (in Wolfermann, 2009) had a closer look at the connection between the number of phases and the capacity of signalized intersections and concluded that from empirical data, that conclusive results cannot be drawn. Very recent research on the topic, not only has shown valuable results to prove that intergreen times have an effect on the capacity on signalized intersections (Wolfermann, 2009), but that this is indeed a topic that require more research and that more evidence would be required.

Other relevant recent publications on the topic of phase order are presented by De Schutter (De Schutter, 2001) and Beauchamp-Baez (Beauchamp-Baez, Rodriguez-Morales, & Muniz-Marrero, 1997). The first is an advance investigation, in which Extended Linear

Complementarity Problem formulation is applied to signal switching sequences determination of the optimal switching time instants, in an acyclic way (De Schutter, 2001). The second involves the selection of the next phase based on a fuzzy logic based Phase Sequencer to select the next phase among the possible ones, in addition to the decision of when to change a phase (Beauchamp-Baez, Rodriguez-Morales, & Muniz-Marrero, 1997).
but the capacity reduction caused by intergreen times needs further consideration. NOYCE ET AL. (2000) also revealed an influence of stage sequence on start-up lost times.

Intergreen times in traffic signal phasing

Traffic lights were initially introduced to regulate movement along conflicting directions in busy intersections. They allow the simultaneous use of intersection by separating conflicting movements in time (Federal Highway Administration, 2004) i.e., compatible movements are organized in the same phase. The design of a traffic signal comprises the calculation of parameters such as cycle length, phase sequence, green time, amber time, and all-red time (Beauchamp-Baez, Rodriguez-Morales, & Muniz-Marrero, 1997).
It is also necessary to regulate the transition between the various traffic phases. This transition is called intergreen time and is defined as the period between conflicting green phases, and it is composed of the yellow interval plus an optional all-red interval, both necessary for clearing an intersection of one traffic stream before allowing another conflicting stream to proceed (Liu , Herman, & Gazis, 1996); (Beeber, 2011); (TRB, 2000).
When the light changes from green to yellow, drivers perceive the meaning of the change and decide whether they are able to safely stop, or if they should continue through the intersection. The yellow time is the period in which drivers can safely stop, including a reaction time of moving their foot off the accelerator and apply the brakes (Beeber, 2011) or safely pass the intersection. The exclusive function of the yellow change interval shall be to warn traffic of an impending change in the right-of-way assignment (Federal Highway Administration, 2012). The duration of yellow time is dependent on the velocity and the gradient of the approach.
Reaction time has widely being studied. From reviews the reaction time of motorists, found that this time is between 1.2 s and 1.4 (Chang, Messer, & Santiago, 1985); (Beeber, 2011). Also a reasonable and comfortable deceleration rate has been considered around 8 to 10 ft/sec^2 (2.4 to 3.0 m/s^2).
Safety at signalized intersections depends on many of factors. Besides the layout of the site, the traffic volumes at the approaches, the phasing, and the human behavior of both drivers and pedestrians, the time settings of the traffic signal are important (Papaioannou, 2007). Proper timing of intergreen times is essential to intersection safety (Beeber, 2011). Very short yellow times can cause rear crashes due to the abrupt detention of drivers familiar with the intersection who know that they would not be able to clear in this period. According to Zador et al. (Zador, Stein, Shapiro, & Tarnoff, 1985) too short clearance intervals lead to larger than average crash rates. Not properly calculations of intergreen times can produce either rear end crashes (due to abruptly stopping) or right angle or frontal crashes (due to premature red end of other groups). Therefore Beeber (2011) suggested the possibility of extending the yellow and all-red signal phases to increase safety and reduce costs in red-light camera enforcement program (Beeber, 2011). However, Wolfermann (2009) states that

safety and efficiency do not necessarily have to be contradictious, and states that high safety can be achieved even when seeking low intergreen times (and thus higher capacity).

North American approach

This approach is based on the principle of calculating the time for the clearance of the last exiting car before permitting the entrance of the conflicting movements. This time interval is called *change interval* or *change period,* and consists of the required yellow time and sometimes an all-red. Different agencies apply different expressions for calculating these clearing intervals, but all are based on the same principles: A time for the driver's reaction, plus a time to approach the stop line (because the car was not able to safety stop before light turns to red) and the time necessary to clear the intersection. Papacostas (Papacostas, 2001) presents in the simplest form for calculating the *change interval* (τ_{min}), where δ_2 is the reaction time, v_0 is the speed of the approaching vehicle, a_2 is the deceleration rate, W is the intersection width and L is the length of the vehicle, in equation 1.

$$\tau_{min} = \delta_2 + \frac{v_0}{2a_2} + \frac{W+L}{v_0} \tag{1}$$

Similar to this, the Federal Highway Administration (Kell & Fullerton, 1998) recommends calculating the *change period* (CP) as shown in the equation 2. Note that this expression is basically the same as equation 1, but it considers the gradient of the approach (g) in the calculation.

$$CP = t + \frac{V}{2a_2+64.4g} + \frac{w+L}{V} \tag{2}$$

The method for calculating the change period is well defined, but there are different criteria for defining whether or not to use the all-red time, and if required, how to split the CP between yellow and for all-red times. The FHA suggests that for change periods longer than 5s, a red clearance interval is typically used. The Manual Uniform Traffic Control Devices (MUTCD) (Federal Highway Administration, 2012) does not provide a method for specific yellow or all-red time calculations, but provides guidance that the yellow change interval should be approximately 3s to 6s. Some agencies use the value of the third term (in equations 1 and 2) as a red clearance interval (implying that the two initial terms of the equation sum up the yellow time). The FHA remarks that in large intersections and on higher speed facilities, clearance intervals are typically higher and thus the changing period is longer.

German approach

Traffic engineering in Germany has a long tradition (Brilon, 2002). One of the main differences between the traffic signal timing plan calculations between the North American approach and the German guidelines (RiLSA) is precisely the way in which the time required to change phases of conflicting movements is defined.
Equivalent to the changing interval in the North American approach, the RiLSA guidelines define the *intergreen* time as "the interval between the end of the green time for one traffic

stream and the beginning of the green time for the next, crossing or entering traffic stream (Road and Transportation Research Association, 1992). Roughly there are no differences in this concept itself, but the way to define the beginning of the green time for the incoming flow is different. Instead of waiting the complete clearance of the last exiting car, before turning to green for the entering traffic, this method considers the trajectories of the exiting and the entering movements to the worst conflict area within the intersection, in order to calculate safe operation, based on kinematic straightforward techniques. The conflict area of conflicting movements is the jointly surface where both trajectories overlap. Those times are calculated for all movements and summarized in a intergreen times matrix.
According to RiLSA, intergreen time t_Z is equal to overrun time ($t_{\ddot{u}}$), plus clearance time (t_r), minus entrance time (t_e) (Retzko & Boltze, 1987):

$$t_Z = t_{\ddot{u}} + t_r - t_e \tag{3}$$

The clearance time is the time necessary for the last vehicle passing the stop line (just before it turns to red) to drive the clearance distance. The clearance distance (L_r) is the distance from the stop line to the conflict area, plus the length of the vehicle (L_v). For straight-ahead movements it is calculated as:

$$t_r = \frac{L_r + L_v}{v_r} \tag{4}$$

The entrance time is the necessary time for the first vehicle of the beginning green to drive from the stop line to the conflict area. In the following formula it recommended by RiLSA for light vehicles (40 km/h).

$$t_e = \frac{3.6\ L_e}{40} \tag{5}$$

It is important to remark that there are some safety factor (buffer times) in both entrance and clearance times, that might consider eventual imprudent of negligent behavior of drivers. For straight-ahead movements, the guidelines apply v_r=10m/s as the clearing speed, which is lower than the speed limits in main urban roads (at least 50 km/h), and additionally the entering time assumes that the entering car, which frequently is in standstill condition when the light turns to green, will pass at a speed of 40 km/h the stop line.
The overrun time is the time between the end of the green time and the point in time at which the last vehicle of the ending green time passes the stop line. It is in most cases the same amber time (between green and red). This implies that the last exiting car, after passing the stop line (just before light turns to red) will be occupying the interaction in spite of the fact that the light is in red. Yellow time (t_G) is defined only by the permissible speed of the access. The minimum amber time is set to 3 s. Amber time is larger if permissible speed is higher:

- $t_G = 3$ s at permissible speed of 50 km/h, or lower
- $t_G = 4$ s at permissible speed of 60 km/h,
- $t_G = 5$ s at permissible speed of 70 km/h.

Context

Bogotá currently has around 1,100 signalized intersections, still based on fix time programming. City residents (more than 7 million inhabitants) experience severe traffic

congestion (Ardila & Menckhoff, 2002). Under a disheartening future, enshrined in an explosive motorization growth and increasing mobility rates, any improvement towards capacity increase and efficiency will be highly desired.

This research was inspired on a four-leg intersection in north Bogotá, Colombia. We observed, that changing the order of the phases, could result in a reduction in intergreen times and thus in an increase in the number of vehicles passing through the intersection per hour. We actually only adopted the geometry of the intersection for the experiment (see Figure 1 and Figure 2). The main characteristic of the geometry is the presence of a 12m median in the E-W direction (Calle 94). This feature is important for this experiment since it heavily affects the entering and clearance times of different traffic groups. Understanding the context in this case will serve to understand the practical implications of a capacity increase due to phase order changes for the city and for other developing cities.

Figure 1 Photograph of the intersection

PROBLEM DEFFINITION

The research is divided into two parts: (a) the computation of intergreen times and the analysis of phase order on the effective green times and (b) the assessment on capacity improvements due to phase sequence changes. Notice intergreen matrix can be calculated analytically. In the first part of the results section in this paper, we present the processes to find the better phase combination. In the second part we measure the differences in capacities for different phase sequences in the intersection. Microsimulation will be used to uncover the isolated effects of phase changing on capacity.

Intergreen minimization

Since the North American approach considers the complete clearance of exiting stream before turning to green entering lights, the order of phases is irrelevant. For the German approach, conflict areas of different exit-enter pairs of signal groups are located in different parts of the intersection, implying different (shorter or longer) t_r or t_e times for conflicting signal groups, and thus different intergreen times. Therefore, timing calculation for signalized intersection under the German guidelines imply summarize all the intergreen times in a matrix.

Intergreen times have to be subtracted to the total cycle time to obtain the effective green times. Only the geometry of the intersection and the speed limits on the approaches have effects on the total intergreen time duration, hence intergreen times are independent on the cycle duration. It means that reducing these transition times implies an increase in effective green time. In order to reduce intergreen times in a given intersection, it is necessary to find the combination of signal groups that: (a) reduce clearance times and (b) have large entering times ($t_{ü}$ is constant as long as the speed limits of the approaches remain constant as well as the gradients). In other words:

$$(t_c - t_e) \rightarrow min \tag{6}$$

To illustrate the differences that can occur in phase sequences, two situations are presented in the selected intersection. In Figure 2, an entering car 1, traveling N-S at a speed v_1 passes the stop line exactly before it turns from yellow to red. While car 1 is crossing (L_d), the light in the access of car 2 turns from red to red-amber, and after one second to green, i.e. while car 1 is crossing the clearance distance, car 2 can enter the intersection at a speed v_2. So, by the time car 1 have cleared the conflict area, car 2 would be approaching it.

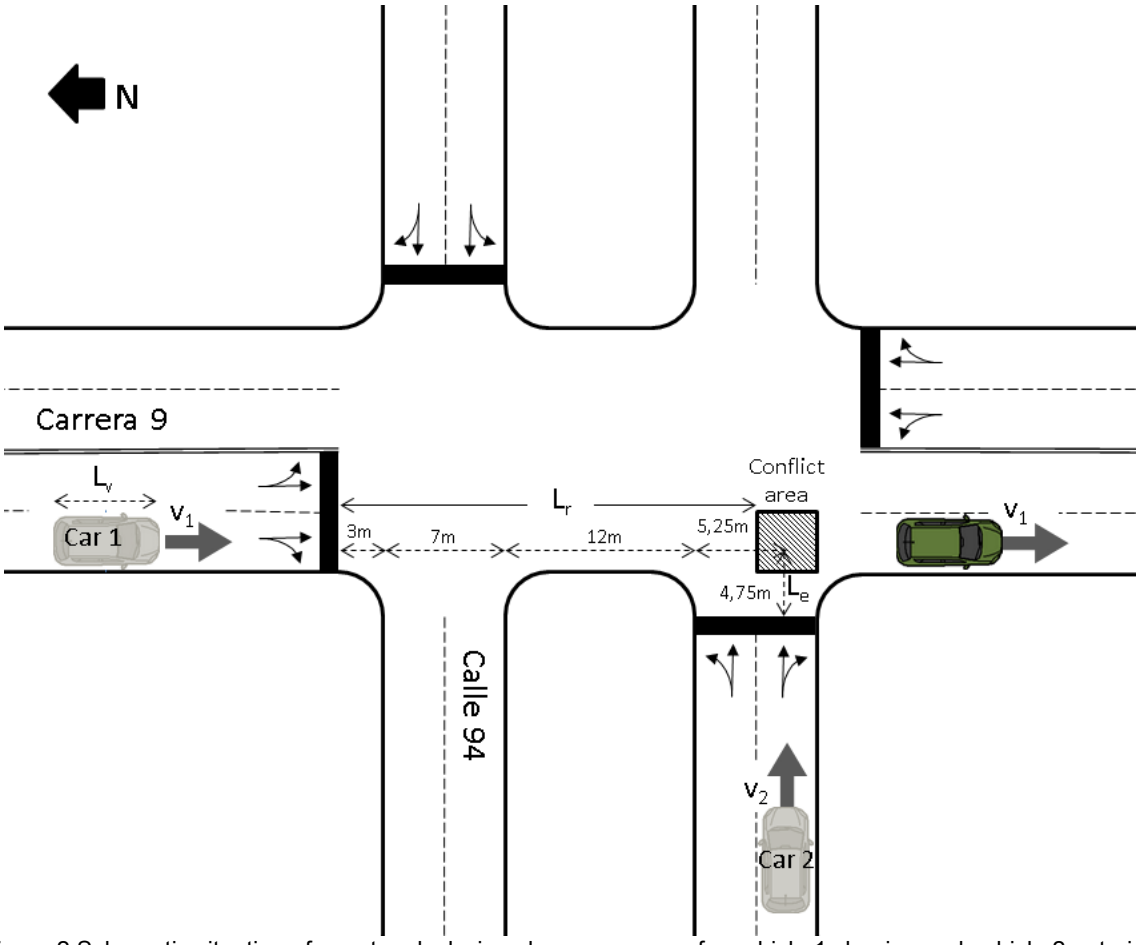

Figure 2 Schematic situation of counter clockwise phase sequence for vehicle 1 clearing and vehicle 2 entering

Let see what would happened for the same N-S car, if the phase sequence changes. In this new situation car 1 is leaving the intersection and the car 3 is entering (Figure 3). In this case the clearance distance L_r is shorter than the entering distance L_e. So it is possible that the traffic light of the car 3 turns to red-amber before the traffic light of the car 1 turns to red, and both cars crosses the intersection safely.

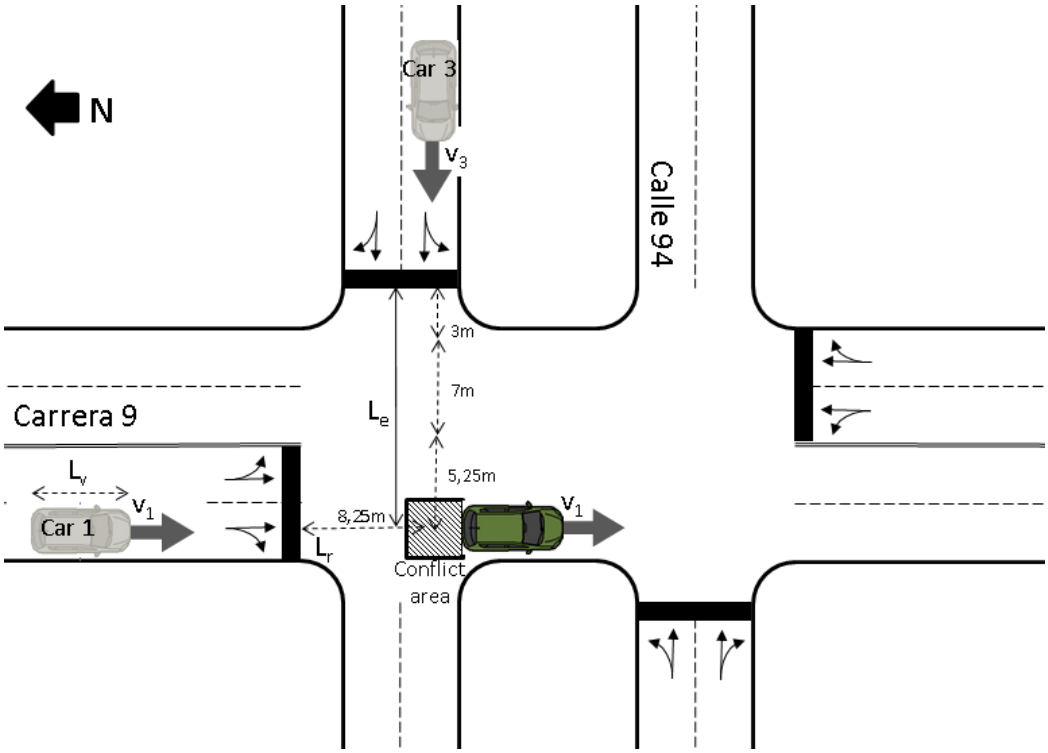

Figure 3 Schematic situation of clockwise phase sequence for vehicle 1 clearing and vehicle 3 entering

Micro Simulation

Unlike intergreen times, the capacity calculations depend on many variables (e.g. traffic composition, randomness of traffic, lane changing, turning flows (proportions), gradient, lane width, degree of knowledge of the intersection by drivers, pedestrian treatment, bicycle or transit presence, and all the other possible factors that affect the outflow rate of each approach). Krüger (1985) could not find from empirical data neither a direct relationship between the capacity of the conflict area and the intersection capacity nor a relationship between the number of stages and the capacity (in Wolfermann, 2009). How to account for instance the higher saturation flow rates due to perceivably greater traffic pressure (leading to a more aggressive driving) presented by Noyce (2000)? These two examples are the main reasons why we decided not to use actual count on streets, but instead to use microsimulation. Another practical reason is the legal constraint in Colombia to program traffic lights with intergreen times less than 4 sec, even having the willingness of the traffic authorities to cooperate in our research.

Experimentation allows researchers to systematically vary certain explanatory variables in order to measure the effect on a dependent variable. Microsimulation permit recreating extreme situation that would be very difficult in reality. Pure effects of phase ordering on capacity will be attained by adopting some reasonable simplification and by running a “before and after” cases of the experiment. So, the only parameter that will vary is the order of phases i.e., the intergreen times. In the software, we performed a straightforward count evaluation in each of the entrances of the intersection (passing the stop line), in order to determine the number of vehicles that can operate in an hour.

To keep constant some other parameters some simplifications and assumptions are required. The approaching speed was defined 50km/h. The geometry was slightly changed to have symmetry, e.g. stop line setbacks were set at 3 m for all accesses. The traffic signal plan was designed with equal green times for each access. A cycle time of 90 seconds was selected for all the simulations. In regard to the turns, we arbitrarily defined 60% of traffic for straight movements and 20% for left and right turns each. As long as any traffic composition can be converted into equivalent light vehicles, we assumed all traffic input to be automobiles. Finally we decided to maintain saturation flow for every green period during the simulation, based on the rationale that capacity at a signalized intersection is based upon the concept of saturation. By considering saturation flows in each access we assure to have the maximum discharge per access in every simulation, thus making results comparable.
The microsimulation software that was utilized for this research is PTV-VISSM. Figure 4 represents this experimental situation.

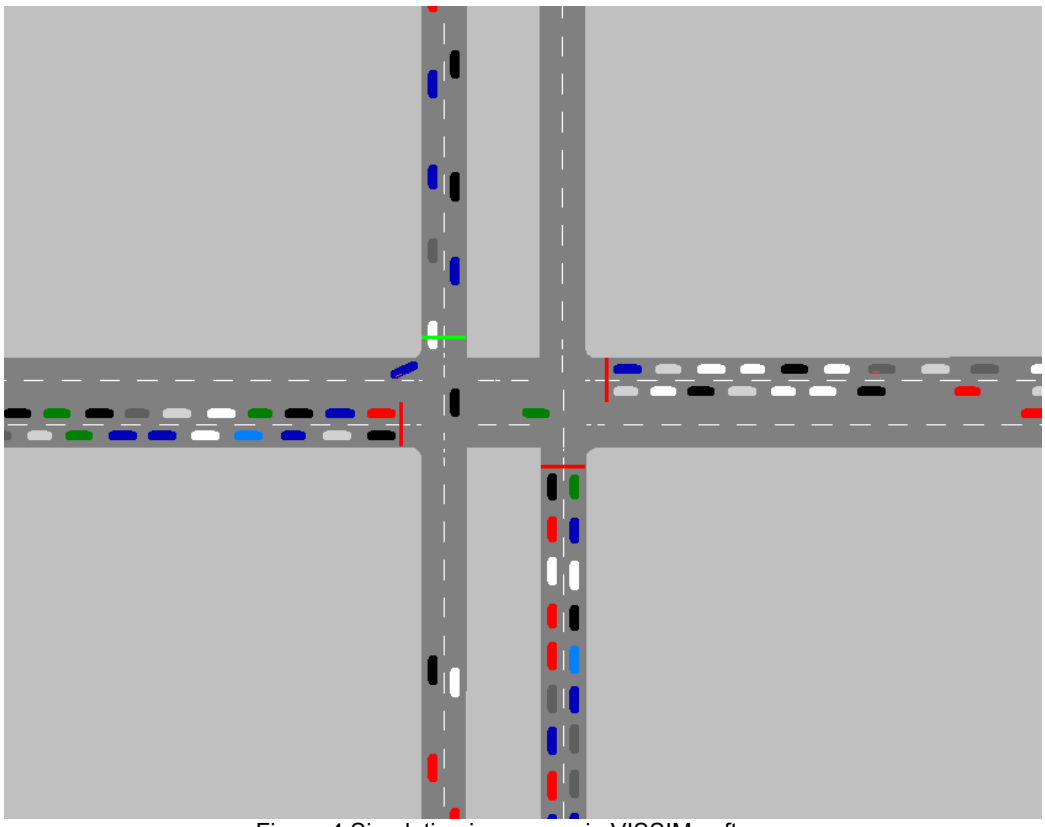

Figure 4 Simulation in process in VISSIM software

When construction traffic simulation models, there are three procedures that has to be considered: (a) a network warming-up time prior staring the evaluation or pre-charge, (b) repetition of several random simulations of the same situation are required (to take into account the randomness of traffic simulations), and (c) calibration according to the site specific drivers behaviour. A pre-charging vehicle input of 1,400 veh/h per access was applied and 900 veh/h per access for the evaluation period. We applied the formula presented by Hollander and Liu (Hollander & Liu, 2008) to determine the number of runs:

$$R = \left(\frac{s.t_{\alpha/2}}{x.\varepsilon}\right)^2 \tag{7}$$

R, required number of model runs;
s, standard deviation of the examined traffic measure;
x, mean of the traffic measure; ε, the required accuracy, specified as a fraction of x;
t_(α/2), critical value of Student's t-test at confidence level ∝.

Usually, R varies from 1 to 20 model runs (Hollander & Liu, 2008). Note that the standard deviation s and the mean x are dependent on the number of runs. This implies to have an iterative process. After three iterations, R converged to R=13 for 99% of confidence. In regard to the calibration parameters of the VISSIM, we applied the values obtained by Ortiz (Ortiz, 2010) in the VISSIM.

RESULTS PART 1: INTERGREEN TIMES CALCULATION

The first step is to name all the movements of the intersection. Figure 5 summarizes the names of all movements. The second step is to calculate all intergreen times. Results are contained in

Table 1. The third step is to evaluate all possible phase combination (the possible number of phase combination is given by factorial formula: (n-1)! where n is the number of phases in the plan (n=4), yielding to 6 possible combinations.

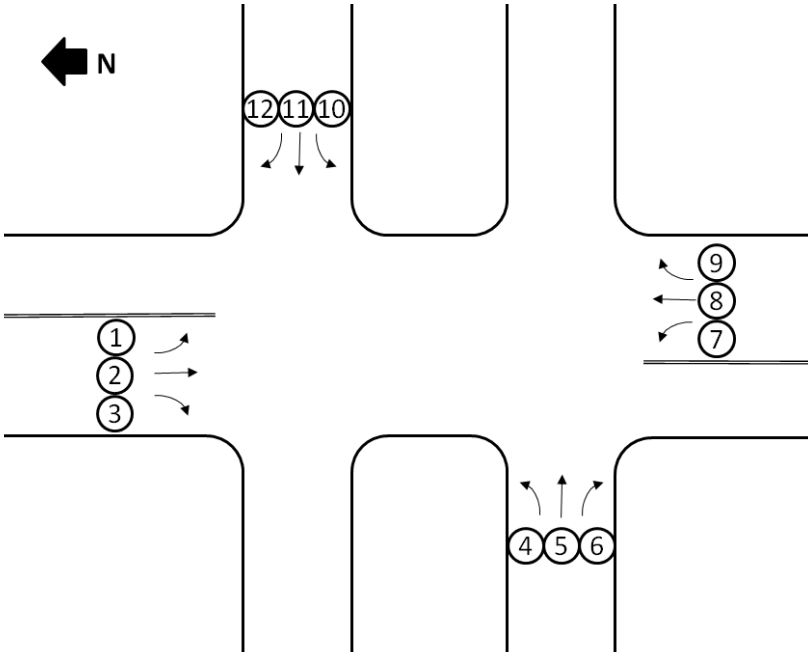

Figure 5 Definition of movements in the intersection

Table 1 Intergreen matrix (in seconds)

		Entering							
		1	**2**	**4**	**5**	**7**	**8**	**10**	**11**
Clearing	**1**		-	4	5	4	5	4	4
	2	-		4	6	4	-	4	4
	4	4	4		-	4	4	4	6
	5	3	3	-		5	5	3	-
	7	4	5	4	4		-	4	5
	8	4	-	4	4	-		4	6
	10	4	4	4	6	4	4		-
	11	5	5	3	-	3	3	-	

In Figure 6 there are defined the movements per phase. With the results of the intergreen matrix, it is easy to define the highest time between two phases. So, it is calculated the sum of each intergreen times for the different phase sequences. The results are computed in Table 2.

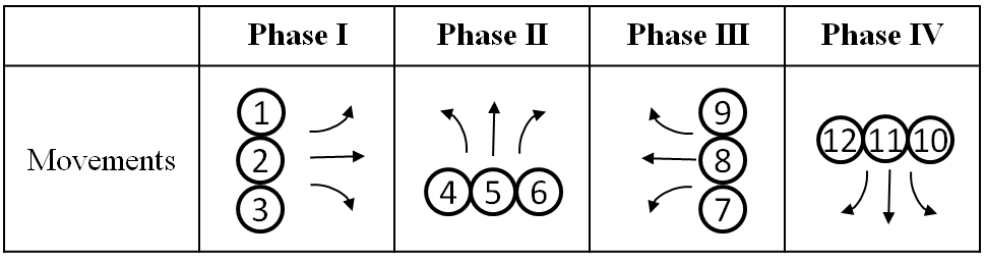

Figure 6 Description of movements related to each phase

Table 2 Sum of intergeen time by phase sequence

Case	**Phase Sequence**				$\sum_{i=1}^{4} t_Z\ (s)$
1	I	II	III	IV	22
2	I	II	IV	III	20
3	I	III	II	IV	19
4	I	III	IV	II	21
5	I	IV	II	III	20
6	I	IV	III	II	16

As we can see the results, the phase sequence most frequently utilized in reality (number 1) has the longest sum of intergreen times. Meanwhile, the best performance occurs for case number 6, when the phase sequence is in clockwise order. The total green time gain, between the worst and the best case, is 6 seconds per cycle, i.e. 1, 5 seconds per access.

These two cases (best and worst) were selected to be simulated in VISSIM. For a given cycle time of 90 s (assumed), the effective green time (G) for the worst case is $G_{case\ 1} = 90 - 22 = 68s$ and for the best case $G_{case\ 6} = 90 - 16 = 74s$. Since signaling times require integer values (in s), for case 6 it was not possible to obtain an even distribution of green times among all four approaches. For case 1, all accesses have 17s of effective green time and in case 6, north and south accesses have 18s and east and west accesses have 19s of green time.

RESULTS PART 2: CAPACITY IMPROVEMENT AND OTHER BENEFITS

Benefits for improvements in traffic engineering and public works are composed by safety benefits, operational benefits, and environmental benefits (National Cooperative Highway Research Program, 2010). Operational benefits of the measure are quantified as enlarged capacity, in terms of the total number of cars that can use the intersection in one hour (Table 3) reduction in person-hour of delay, less stops and a lower probability to be stopped (i.e. to wait one more cycle to pass) (For accesses 1 and 3, one second increase of the green time represents almost 5% increase in the capacity. For accesses 2 and 4, the increase of two second of green per cycle represents in the hour more than 10% in discharge. For one hour, we got 266 more cars passing the intersection, which means a 7.8% of capacity increase (based on all simulations). To make results independent on this case, we can say that there is an increase of 66 vehicles per hour per approach, or 33 vehicles per line per hour.
Table 4). This positive difference will represent not only gains in time for all users, but also reduction of costs to the public in terms of lost productivity. However, in this case, the measure has been tested in a theoretical way, and therefore the values of For accesses 1 and 3, one second increase of the green time represents almost 5% increase in the capacity. For accesses 2 and 4, the increase of two second of green per cycle represents in the hour more than 10% in discharge. For one hour, we got 266 more cars passing the intersection, which means a 7.8% of capacity increase (based on all simulations). To make results independent on this case, we can say that there is an increase of 66 vehicles per hour per approach, or 33 vehicles per line per hour.
Table 4, only show the evaluation in a 50 meters length segment upstream each stop line. Rather than showing absolute values, these figures show what we intuitively suggested before: the increase in effective green time, caused by reduction in intergreen times, reduces delays and stops.

Table 3 Traffic performance of the Intersection in the two Extreme Situations

		N	Case 1 (worst)		Case 6 (best)		Variation
			Mean (veh)	Standard deviation	Mean (veh)	Standard deviation	
Discharge rate (veh)	**Access 1**	13	791.5	14.3	830.9	14,7	4.75%
	Access 2	13	785.5	10.7	877.5	10.4	10.48%
	Access 3	13	793.4	11.5	835.4	15.8	5.03%
	Access 4	13	788.9	9.7	881.2	9.6	10.47%

For accesses 1 and 3, one second increase of the green time represents almost 5% increase in the capacity. For accesses 2 and 4, the increase of two second of green per cycle represents in the hour more than 10% in discharge. For one hour, we got 266 more cars passing the intersection, which means a 7.8% of capacity increase (based on all simulations). To make results independent on this case, we can say that there is an increase of 66 vehicles per hour per approach, or 33 vehicles per line per hour.

Table 4 Average Delay of Intersection in the two Extreme Situations

	Improvement
Delay per vehicle (s)	9,91%
Time stopped per vehicle (s)	10,51%

Number of Stops per vehicle	7,11%

The environmental benefits caused by any transportation projects are mainly related to the reduction in the consumption of resources (in this case fuel) and improved air quality (less emissions causing less exposition of drivers and pedestrians). Due to changes in the order of phases no reduction in crashes within the project area are expected. Assuming the inter-green calculation to be properly made, there is the same level of safeness (or same risk) in case 1 or case 6.

CONCLUSIONS

This research proved that the phase sequence could have a considerable increase in the capacity of a signalized intersection. The results based on micro-simulations, for this specific case, yield to increases of 7.8% in the hourly discharge and a net effective green time of 6 seconds was gained. More general, we found an increase of 66vehicles per approach per hour. However, the applicability of the results presented in this document are restricted to split phased intersections and to wide intersections (where there is potential of differences in entering and clearance times, depending on the phasing sequence).

Note that this extra capacity can be attained only by programming the traffic lights. While actuated signal controllers require very expensive technologies to maximize number of vehicles passing by variable green allocation for phases according to the demand (an efficient use of green times), this presented technology saves resources.

This principle can contribute to select the most suitable changes of phases within a cycle, independent whether it is for fixed time or for actuated controllers. In cases of prioritization of transit movements, which usually interrupt the normal operation of the intersection, thinking about the preceding phase, under criteria of reducing intergreen times can also be possible.

There are strong differences in the way of considering the intergreen times in the German and the North American approach. There are two main differences. Firstly, RiLSA guidelines permit nil or negative intergreen times and secondly RiLSA do not require that the last clearing car abandon completely the intersection in order to permit cross-traffic to enter. However, German guidelines omit two important factors in regard to yellow times. Sccording to the he Institute of Transportation Engineers (ITE) it seems to be sensible to consider actual approaching speed (85th percentile approach speed), rather than the speed limit, and to consider the gradient of the approach, which clearly affects the deceleration capability of vehicles.

In terms of road safety the order of phases has implications. Having counter-clockwise phase order implies that in a cross four-leg intersection always the entering vehicle approaches from the left-hand side of the clearing vehicle. Note that U-turns are not allowed, because in case the latest clearing vehicles makes a U-turn, it will meet the entering car in a frontal way. This would require an increase in intergreen requirements, and the gain attained by this new phase arrangement (clockwise) would be lost.

From this research arose also the discussion about its application in developing countries. The frequent violations of speed limits in developing countries and the lack of enforcement, put engineers in the challenge of designing signaling for these extreme situations. Considering Greece as a developed country, it was found by P. Papaioannou (2007), that

85th percentile of speed at the study site was 63km/h given a speed limit of 50km/h, while the maximum speed found to be 100 km/h. This means that the study of overrun time and yellow, taken from RiLSA guidelines should be subject of more research.

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