ISSN (e): 2250 – 3005 || Volume, 09 || Issue, 2 || February– 2019 ||
International Journal of Computational Engineering Research (IJCER)

# Sustainable traffic circulation at controlled intersection

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***ABSTRACT:***

*Traffic circulation is the activity that consumes most energy in Morocco, and is one of the main sources of gas emissions and greenhouse effect, causing congestion and generating noise. The current model for traffic management is unsustainable, it's fundamentally based on motorized transport and, specifically, the use of private car. In this paper, a typical four-legged intersection is studied with the aim of improving the control signal, we will evaluate the level of service, we calculate the optimum cycle time, and we will examine this result by applying the queuing theory. The validation of the optimal cycle time is approved through the comparison of the performance parameters.*

***KEYWORDS:****Sustainable mobility, Webster formula, queueing theory, controlled intersection, Tangier city*

Date of Submission: 20-02-2019 Date of acceptance: 08-03-2019

## I. INTRODUCTION

Sustainability is at the heart of mobility strategy, and it's a key challenge, and it's essential therefore to know how it can be measured. What strategies are available to improve the sustainability of mobility? On the one hand, action can be taken regarding the supply of, zone design and car flow in order to modify behaviors of users. In literature there exist several attempts to change mobility, to make it more sustainable [1], [2].

Various research and developments projects have examined urban mobility from various standpoints. Frequently discussed areas of study include; the role of spatial planning and land use, which can explain mobility concept and implementation of sustainable urban transport [3], market segmentation of urban mobility or mode of transit integration to other mode. The challenge for today's cities is to reduce transports needs, increasing the local economic prosperity and quality of life [4], [5].

The delay caused in an intersection is one of the most important parameters in determining the level of service offered. Delay models at intersections are determined through deterministic (fluid theory of traffic flow) or stochastic (random traffic flow, using steady-state queuing theory) models. The first models adopted in this area is the steady-state queuing theory to estimate delays and queues at intersections [6]. The methodology followed in stochastic delay studies is, steady-state models using exact expressions or approximate expressions widely developed by Webster [7]. Time dependent delay models or theory of actuated and adaptive signals which in turn is structured in, theoretically-based expressions and approximate delay expressions [8].

Each method is related to the level or time interval of collected data, the behavior of vehicle's flow, and according to the hypotheses admitted in the study [9].

Researchers have developed a wide range of queuing theory applications in traffic flow theory, specifically, at controlled intersections where queues are formed, in turn causes congestion and polluting emissions. Schitter and Moor [10], they have used linear programming to minimize waiting time and queue length, where developed a model which describes length of queue evolution at each access as a function of time, and how it can determinate the optimal switching cycle where the red-green time can vary from one cycle to another. Hamiruce and Yusof in [11], the model adopted is an M/M/1 queueing theory for single intersection, developing average time waiting and length queue using optimization technique, Markov decision, also this technique used in [12]. B. Mirchandani and Ning Zou [13], have elaborated a numerical algorithm to compute steady-state performance measures (delay and queue length). Many authors have been interested in the M/M/1 model, calculating performance measures [14,15,16,17,18], reducing vehicle queue waiting time by using Montecarlo algorithm [21], others comparing the different models M/M/N [19,20], determine performance parameter by

using the maximum likelihood method [19]. Patel and Bhathawala, have used the queuing theory to choose the best path that minimizes the total time of the system, based on traffic light state [22].
In this study we will analyze the traffic flow in the northern region of Morocco, Tangier city, which has received an ambitious slate of projects between 2010 and 2017 [23]. Also the population has evolved from 762583 in 2004 to 1160302 in 2014 [24], this evolution is reflected in the generation of more complex mobility, the creation of new bus lines, increased taxis and travel, and a high rate of industrialization. All these factors will contribute to an increase in traffic congestion [23].
The work is based on the study of the cycle time at a typical four-legged controlled intersection, determining the optimal cycle, and through the queuing theory we can find out the goodness of this new cycle time.

## II. METHODOLOGY

Tangier city knows a great increase in the number of vehicles as we can observe in figure 2.1 [24], moreover there is a high degree of pedestrians sharing the same place with cars, what causes a congestion in the mobility, therefore the design of the streets should be transformed to satisfy the new situation [25].

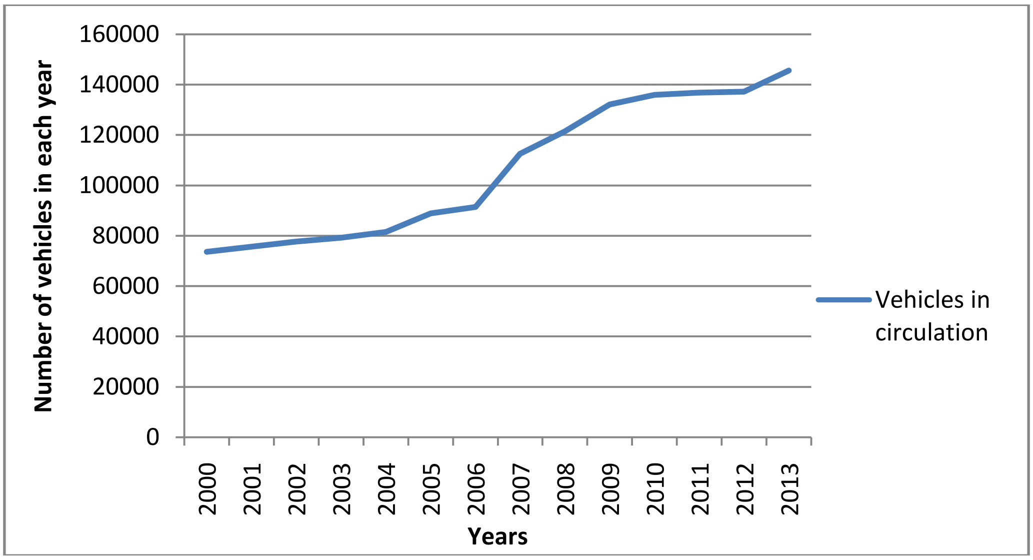



**Figure: 2.1Vehicles in circulation in Tangier city**

First, we study the area where the intersection is located. As we can observe in figure 2.2, the targeted area, is principally constituted by establishment that generate mobility. In the east, shopping centers, which create a great flow of pedestrians, in peak hours, in the north there are cafes and restaurants, in the south and west hospitals also in the center of study area there are 2 schools, all these activities create a very complex mobility.

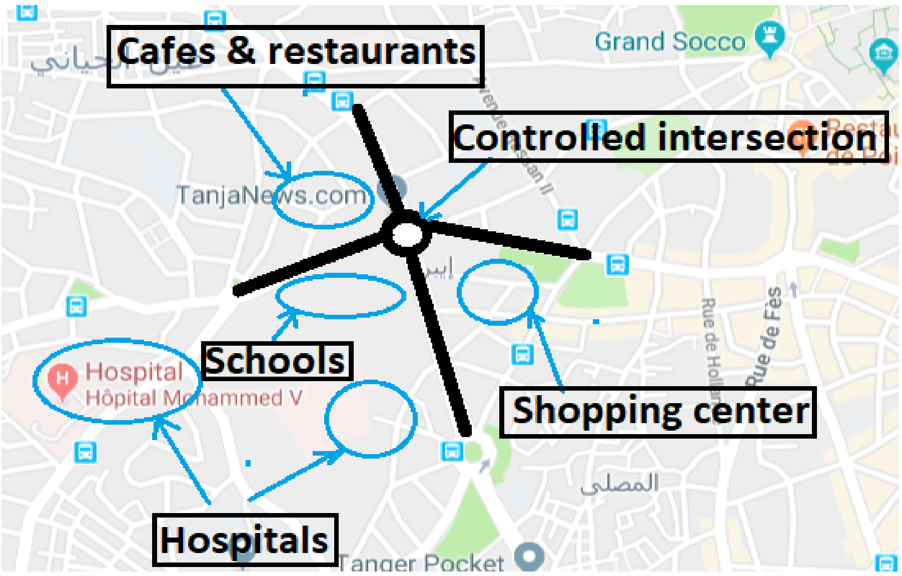



**Figure 2.2Study area and characteristics**

We delimit the region of study, modeling the study area using a graph, to make an adequate inventory and facilitate the work, where the edges present the streets and nodes will correspond the streets intersections [26].
As shown in figure 2.3, each intersection is identified by a letter, and we also identify the direction of circulation.

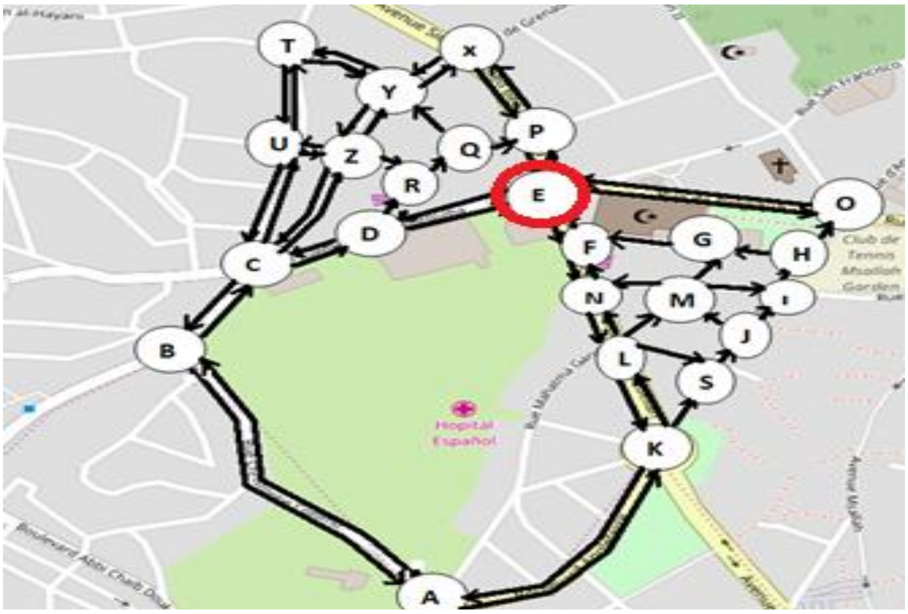



**Figure 2.3 Modeling of the study area**

The node 'E' in the graph is a controlledintersection by a traffic light, and it is a convergence point of a multitude directions. The aim of this study is to find out, how it affects the cycle time of traffic lights in producing congestion within the roundabout (node "E").
The methodology is based on collected data related to the vehicular flow in the four intersection accesses (in both directions) C→E, P→E, E→O, E→F.The next work will be collecting data related to vehicles circulation at the intersection. We will sort the data in a worksheet, that shows the geometrical characteristics of the intersection, the types of vehicles circulating and the cycle time distribution. We use this data to calculate the capacity of each access, the saturation flow, and other parameters, in order to determine delay and thereforedetermine the level of service LOS.Using Webster's formula, we will calculate the optimal cycle time.
Finally, to verify the accuracy of this optimal cycletime, we use queueing theory to model arrivals and service at each access, and we compare the two distributions of current cycle time and the optimum cycle time, throughperformance parameters.

## III. RESULTS AND DISCUSSION

To find out the best time interval to collect data at the intersection, we represent the vehicular flow throughout the day in the 4 accesses. With the objective, determine the time interval of maximum demand. The result is illustrated in figure 3.1.
According to the figure 3.1 there are three time intervals of maximum flow, morning, afternoon and evening, we choose the interval with the maximum demand, in the afternoon. We evaluate the cycle time to see if corresponds to the current cycle and also the delay induced by evaluating (LOS, Level Of Service). For this, we carried out a mixed count of the vehicles in interval time from 1h00 to 2h30, with a counting during 15 minutes, alternative C [27].

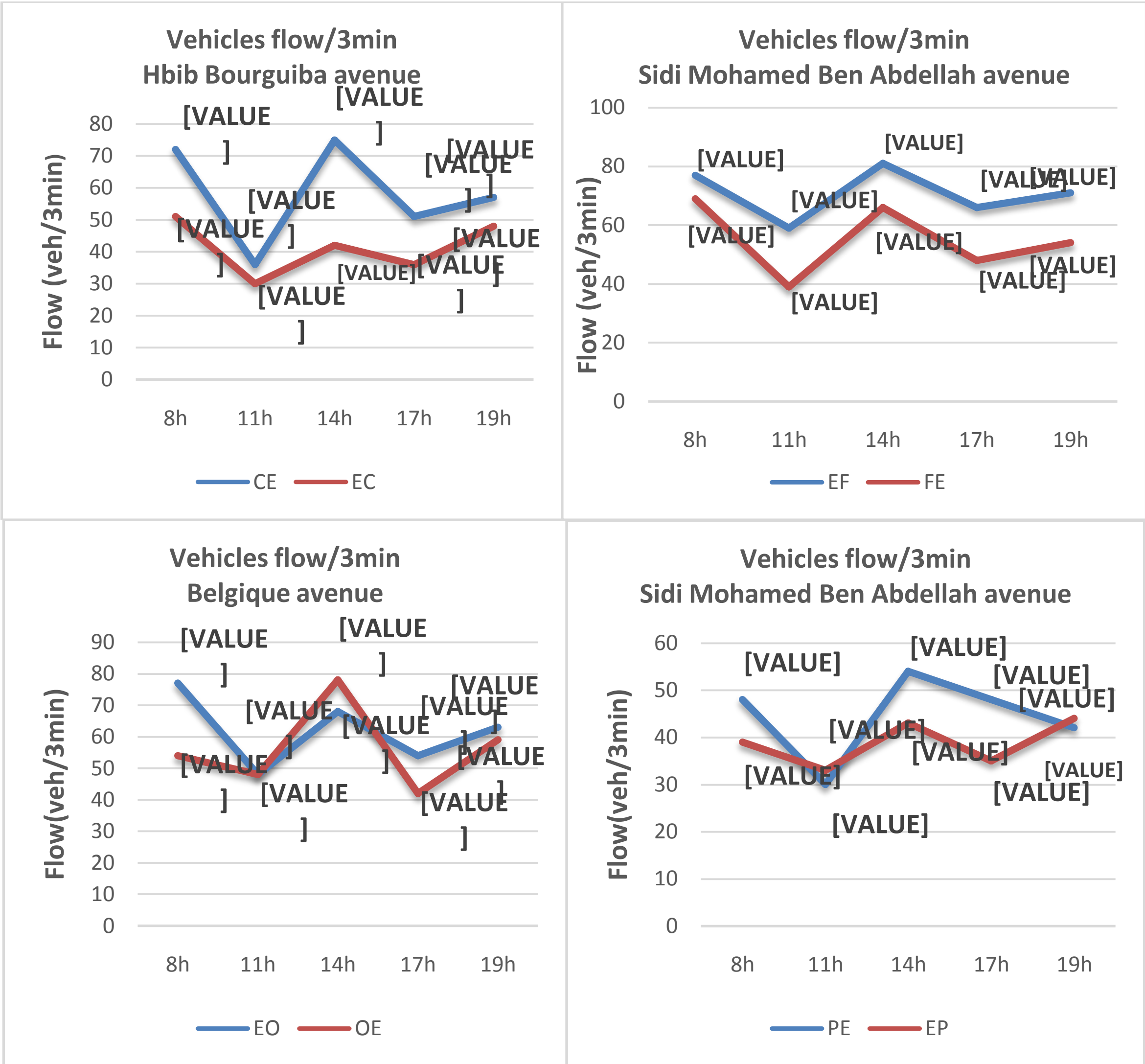



**Figure 3.1 Traffic flow in the 4 accesses**

For a good data analysis, we use a worksheet, as indicated in figure 3.2, which contains necessary information to identify the intersection.
The traffic light time is distributed over two phases, with the current cycle time is 83 seconds, represented as follows:

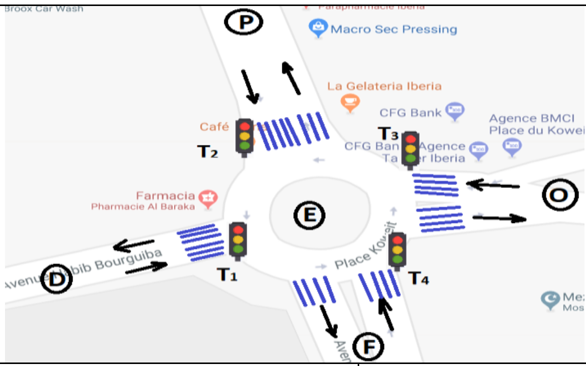
Phase 1: T1=T3, green + amber=42 (s) red = 41 (s) amber = 3 (s)
Phase 2: T2=T4, green + amber=32 (s) red = 51 (s) amber = 3 (s)

With the current cycle time, 41 seconds (red time) for the first phase which represents 50% of the cycle time, and 51 seconds (red time) for the second phase which represents 60% of the cycle time, so more 50% of the total time of the current cycle, cars do not circulate, which leads to more pollutantsemissions[29,30].
The worksheet represents the geometrical characteristics of the intersection, such as the diameter, the width of each access for vehicles and pedestrians. According to Hénard [28]: "The roadway-ring width in a turning intersection must be equal to a quarter of widthsroads sum". in our case, as illustrated in figure 3.2, the ring must have (10 + 10 + 7 + 7) / 4 = 9 (m), so it is necessary to reduce the diameter by 3 meters.

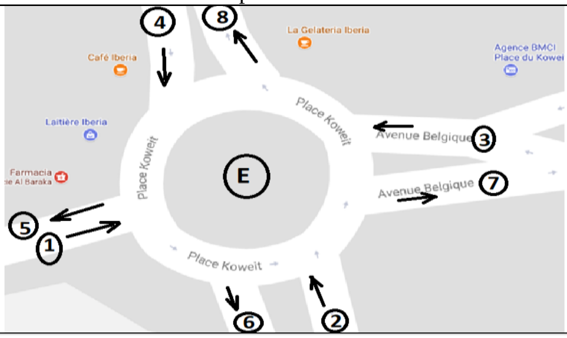
Intersection: **E**

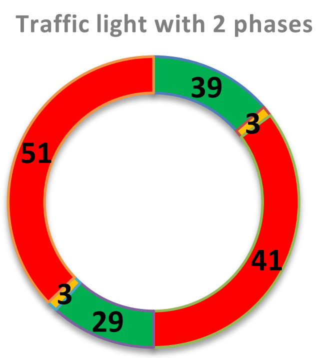
**Characteristics**: Internal diameter 12 (m), Total diameter: 24 (m), ring diameter: 12 (m)
**Access width**: D →E= 7 (m), P →E=7 (m), O →E= 10 (m), F →E= 10 (m)
**Pedestrian crossing width** : $W_{D\to E} = 3{,}5\ (m) W_{P\to E} = 3{,}5\ (m) W_{O\to E} = 5{,}5\ (m) W_{F\to E} = 3{,}5\ (m)$
**Data collection time**: 1h00-2h30

**Location**




Representation




Identification

Collected data : Vehicles/hr

| Beginning | End | Flow | Vehicles | Bus |
|---|---|---|---|---|
| 1 | 6 | 402 | 383 | 19 |
| 1 | 7 | 552 | 543 | 9 |
| 1 | 8 | 270 | 270 | 0 |
| 1 | 5 | 47 | 47 | 0 |
| **1** | **Total** | **1271** | **1243** | **28** |
| 2 | 7 | 297 | 292 | 5 |
| 2 | 8 | 382 | 345 | 37 |
| 2 | 5 | 240 | 237 | 3 |
| 2 | 6 | 37 | 37 | 0 |
| **2** | **Total** | **956** | **911** | **45** |
| 3 | 8 | 423 | 178 | 16 |
| 3 | 5 | 491 | 199 | 14 |
| 3 | 6 | 344 | 180 | 4 |
| 3 | 7 | 53 | 23 | 0 |
| **3** | **Total** | **1311** | **1277** | **34** |
| 4 | 5 | 136 | 135 | 1 |
| 4 | 6 | 475 | 447 | 28 |
| 4 | 7 | 214 | 210 | 3 |
| 4 | 8 | 46 | 46 | 0 |
| **4** | **Total** | **871** | **839** | **32** |

**Figure 3.2 Worksheet to identify the intersection 'E'**

It is necessary to find a new cycle time distribution at the intersection 'E', to optimize the traffic circulation, and consequently to reduce pollutant emissions and congestion [27].

To evaluate the intersection, we determine the level of service (LOS), by calculating the total delay caused by the traffic light.

We calculate the average delay in each accessusing the following expression, Webster delay formula [27,31]:

$$R = 0{,}38.C.\frac{(1-\frac{g}{C})^2}{(1-((\frac{g}{C})(X))} + 173.(X)^2.[(X-1+\sqrt{(X-1)^2+(16.\frac{X}{c})}] \quad (1)$$

With,
g, green time factor
C, cycle time
X, volume-capacity ratio
c, access group capacity

The ideal capacity of an intersection, is considered 1800 (vehicles/ hour/lane) in green time (this value is chosen according to the HCM guide, $S_0 \in [1700,1900]$), the value 1800 is the most used, and also this capacity will be modified by a number of factors, represented in the table 3.1 [27]:

$$C = 1800.N.f_w.f_{HV}.f_g.f_p.f_{bb}.f_a.f_{LU}.f_{LT}.f_{RT}.f_{Lpb}.f_{Rpb}. \quad (2)$$

**Table 3.1 Saturation flow adjustment worksheet**

| *Saturation flow adjustment* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Lane | Ideal saturation flow | No.of lanes | Adjustment factor | | | | | | | |
| | | | Lane width $f_W$ | Heavy Veh. $f_{Hv}$ | Parking. $f_p$ | Bus Blockage $f_{bb}$ | Area Type $f_a$ | Right turn $f_{rt}$ | Left turn $f_{lt}$ | Sat. Flow Ratio**S** |
| 1 | 1800 | 2 | 0,96 | 0,96 | 1 | 1 | 0,9 | 0,987 | 0,985 | 2903 |
| 2 | 1800 | 3 | 0,98 | 0,9 | 1 | 1 | 0,9 | 0,985 | 0,987 | 4167 |
| 3 | 1800 | 3 | 0,98 | 0,95 | 1 | 1 | 0,9 | 0,984 | 0,985 | 4385 |
| 4 | 1800 | 2 | 0,96 | 0,93 | 0.993($N_m$=**27**) | 1 | 0,9 | 0,988 | 0,993 | 2818 |

In table 3.2, we calculate v/s (flow ratio), this parameter used to determine $X_c$ (intersection critical lane group).
$X_c$, to determine the time duration of green in each phase.
v/c, used to calculate delay in the intersection, see table 3.2, also to evaluate, the most critical group of lanes (the largest value).
g/C, green ratio, to determine delay and LOS, indicated in tables 3.3 and 3.4.

**Table 3.2 Capacity analysis worksheet**

| Capacityanalysis | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lane | **1** Adj. Flow Rate v | **2** Adj. Sat. Flow Rate S | **3** Flux Ratio v/s | **4**Green Ratio g/C | **5** Lane group Capacity c, **2x4** | v/c ratio, X**1/5** | Critical Lane Group |
| 1 | 1271 | 2903 | 0,438 | 0,446 | 1295 | 0,981 | yes |
| 2 | 956 | 4167 | 0,229 | 0,325 | 1354 | 0,706 | no |
| 3 | 1311 | 4385 | 0,299 | 0,446 | 1956 | 0,670 | no |
| 4 | 871 | 2818 | 0,309 | 0,325 | 916 | 0,951 | yes |

$X_c$ formula and Y$= \sum_i \left(\frac{v}{s}\right)_i$:

$$X_c = \frac{\sum_i\left(\left(\frac{v}{s}\right)_i\right).C}{C-L} = \frac{0{,}747.83}{83-8} = 0{,}827 \quad (3) \qquad \sum_i \left(\frac{v}{s}\right)_i = 0{,}438 + 0{,}309 = 0{,}747 \quad (4)$$

**Table 3.3 Level of service worksheet**

| Lane | Level of service | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total_Delay=**27,09** (sec/veh) ***LOS= D*** | | | | | | | |
| | v/c | g/C | C | c | PF | $d_1 + d_2$ | LOS | Delay |
| **1** | 0,981 | 0,446 | 83 | 1295 | 1 | 33,53 | D | 33,53 |
| **2** | 0,706 | 0,325 | 83 | 1354 | 1 | 19,85 | C | 19,85 |
| **3** | 0,670 | 0,446 | 83 | 1956 | 1 | 14,43 | B | 14,43 |
| **4** | 0,951 | 0,325 | 83 | 916 | 1 | 44,71 | E | 44,71 |

Depending on the result obtained, it is necessary to reduce the delay in the intersection to have a better LOS service [32].
For this, we will use the collected data to calculate the optimal cycle, and the new distribution of green times.
The optimal cycle $C_0$ using Webster formula:

$$C_0 = \frac{1{,}5.\mathrm{L}+5}{1-\sum_1^n \frac{v_i}{s_i}} \qquad (5)$$

L, lost time per cycle (2 phases L = 8, 3 phases L = 12) [32].
The duration of pedestrian green time, must satisfy some conditions [27, 31, 33], the result is summarized in Table 3.4:

**Table 3.4 Minimum green time for pedestrians**

| The minimum green time for pedestrians in each access | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Lane | $W_E(m)$ | $\frac{Pedestrian}{hr}$ | $N_{ped}$ | L(m) | $S_P(m/s)$ | $\boldsymbol{G_P}$ | $\boldsymbol{G_i}$ | $\boldsymbol{G_i > G_P}$ ? |
| 1 | 3,5 | 276 | 6,6 | 14 | 1,2 | **16,4** | **41** | **yes** |
| 2 | 3,5 | 300 | 7,16 | 20 | 1,2 | **21,5** | **51** | **yes** |
| 3 | 5,5 | 380 | 9,07 | 20 | 1,2 | **21,2** | **41** | **yes** |
| 4 | 3,5 | 240 | 5,73 | 14 | 1,2 | **16,2** | **51** | **yes** |

According to the results obtained, taking into account the current cycle of 83 (s), the duration of pedestrian green time is sufficient, with the minimum time $G_p$.

In our case, we have 2 phases, each phase with two opposite movements, we chose the value that maximizes v/s, of each phase [32]:

$$C_o = \frac{1{,}5.(8)+5}{1-(0{,}438+0{,}309)} = 67{,}2(s)$$

According to Webster, to have an acceptable delay in the intersection [114]:

$$0{,}75.C_o < C_{act} < 1{,}5.C_o \rightarrow 50 < C_{act} < 100$$

The optimal cycle time causes a minimal delay in the intersection.
According to the results of table 3.2, and 3.3, equation 3 and 4, the duration of actual green time is:

$$g_i = \left(\frac{v}{s}\right)_i \left(\frac{C}{X_i}\right) \quad (6)$$

$g_1 = 0.438.\left(\frac{83}{0.827}\right) = 44(s)$ and $g_2 = 0.309.\left(\frac{83}{0.827}\right) = 31(s)$
Where cycle length is : $g_1 + g_2 + L = 83(s)$
The new distribution (optimal)time of the effective green in the intersection (2 phases) is:

$$G_E = T_{C_o} - L \quad (7)$$

$G_E = 67 - 8 = 59$ (s)
Then, the new effective green timedistribution for each phase, using equation 8, illustrated in figure 3.3:

$$g_e^i = \frac{y_i}{y}.G_E \quad (8)$$

$g_e^{1,3} = \frac{0{,}438}{0{,}747}.59 = 34(s)$ $\quad g_e^{2,4} = \frac{0{,}309}{0{,}747}.59 = 25(s)$

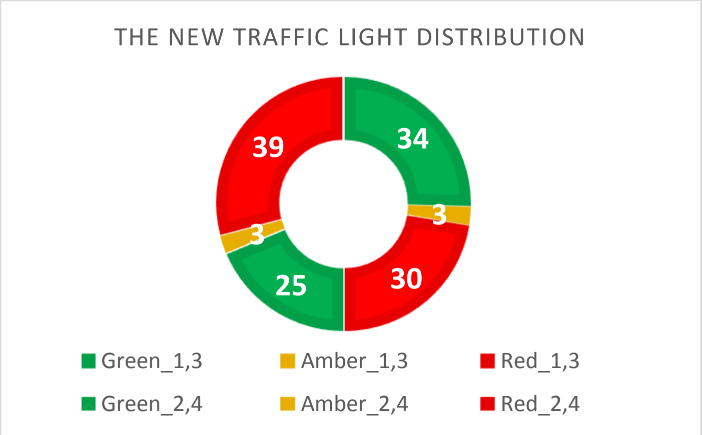



**Figure 3.3Optimal traffic light distribution**

Queueing theory model

We use the queueing theory to check the improvement introduced by the newcycle time distribution. Queuing theory does not solve the problem, but it models the phenomenon and provides vital information for decision-making [35].
The specific objectives for which queue theory has been used consist in:
- Determine the vehicle arrival rate, the traffic light service rate and the service factor.
- The average number of vehicles waiting in queue and in the system.
- The average waiting time in queue and in the system.

The system used to describe the traffic sequence is M / M / 1: FIFO, according to the Kendall notation [35], where the first two letters correspond to distribution of arrival and service, the third value is the number of servers, in our case, one lane, FIFO is the discipline of theservers.The arrival and service rates are considered as Markov models, since they follow a Poisson and exponential distributions for their times.
Equation 9 represents the utilization factor, is the ratio between the demand (arrival rate, λ) and the service capacity (product of the number of servers S, in this case S = 1, by the service rate, μ (vehicles/unit of time)).

The utilization factor: $\rho = \frac{\lambda}{?}$ (9)

The average number of vehicles waiting: $L_q = \frac{\lambda^2}{(\mu-\lambda).\mu}$ (10)

The average number of vehicles in the system: $L = \frac{\lambda}{\mu-\lambda}$ (11)

The average time spent waiting: $W_q = \frac{\lambda}{(\mu-\lambda).\mu}$ (12)

The average time spent in the system: $W = \frac{1}{(\mu-\lambda)}$ (13)

The traffic light cycle at roundabout 'E', is 83 (seconds), with 43 cycles per hour, so the time when vehicles are moving between nodes C, E and between nodes E and O, is 42 * 43 = 1806 seconds.
We also have 31 * 43 = 1333 seconds, the time when vehicles are moving between nodes F, E and E, P, (service time).
Thetraffic lightstime distribution at the intersectionis:

$T_1 = T_3$Green = 39 (s), red = 41 (s), amber = 3 (s)

$T_2 = T_4$, Green = 29 (s), red = 51 (s), amber = 3 (s)

Table 3.5shows the distances between nodes, used to determine the capacity of each street.

**Table 3.5 Distance between nodes in meters**

| Nodes | **E** | **P** | **C** | **O** | **F** |
|---|---|---|---|---|---|
| **E** | 0 | 85 | 320 | 388 | 63 |
| **P** | 85 | 0 | X | X | X |
| **C** | 320 | X | 0 | X | X |
| **O** | 388 | X | X | 0 | X |
| **F** | 63 | 85 | X | X | 0 |

We calculated, the arrival rate "λ" between each node, in the time interval from 10:00 to 11:30 with 5 (min) time of measurements.
We calculate the rate of service or the capacity in each street, C→E, P→E, F→E and O→E, each street with a certain distance and a capacity of vehicles circulating with 10 (m/s), represented in table 3.6.

μ(C→E) = [43*42/ (320/10)]*30 = 1693 Vehicles/hr
μ(O→E) = [43*42/(388/10)]*40 = 1862 Vehicles/hr
μ (F→E) = [43*31/ (63/10)]*8 = 1692 Vehicles/hr
μ (P→E) = [43*31/ (85/10)]*9 = 1411 Vehicles/hr

30, 40, 8 and 9 is the number of vehicles occupying each street or segment, knowing the distance between the nodes and the average traffic speed 10 (m/s) [34].

- W, $W_q$ in seconds, reflect the waiting times of vehicles in all the system and in the queue respectively.
- L, $L_q$ average number of cars waiting in the system and in the queue respectively, the result is summarized in table 3.6, using equations 9, 10, 11, 12, 13.

**Table 3.6 Performance parameters related to congestion analysis**

| | **λ** | **μ** | **ρ** | **L** | $L_q$ | **W** | $W_q$ |
|---|---|---|---|---|---|---|---|
| **P→E** | 1200 | 1411 | 0,850 | 6 | 5 | 17 | 14 |
| **C→E** | 1607 | 1693 | 0,949 | 19 | 17 | 42 | 40 |
| **O→E** | 1740 | 1862 | 0,934 | 15 | 13 | 30 | 27 |
| **F→E** | 1500 | 1692 | 0,886 | 8 | 7 | 19 | 17 |

In each street or segment, the degree of traffic is high, 0.85≤ ρ <1. And according to these values, the street between nodes C and E is the most congested with ρ = 0, 949. This is due to the short length of the street, the high number of cars crossing this street.
To evaluate the previously calculated cycle, C = 67 (s) (optimal cycle), using the same parameters and the new cycle value, with 53 cycles per hour, this gives 37 * 53 = 1961 seconds, the time when vehicles are moving between nodes C, E and between the nodes E and O. We also have 28 * 53 = 1484 seconds, the time when vehicles are moving(service time) between the nodes F, E and E, P.
The new values of the service time are summarized in Table 3.7

μ(C→E) = [53*37/ (320/10)]*30 = 1883 Vehicles/hr
μ(O→E) = [53*37/(388/10)]*40 = 2021 Vehicles/hr
μ (F→E) = [53*28/ (63/10)]*8 = 1884 Vehicles/hr
μ (P→E) = [53*28/ (85/10)]*9 = 1571 Vehicles/hr

**Table 3.7 New performance parameters related to congestion analysis**

| | **λ** | **μ** | **ρ** | **L** | $L_q$ | **W** | $W_q$ |
|---|---|---|---|---|---|---|---|
| **P→E** | 1200 | 1571 | 0,764 | 3 | 2 | 10 | 7 |
| **C→E** | 1607 | 1883 | 0,853 | 6 | 5 | 13 | 11 |
| **O→E** | 1740 | 2021 | 0,861 | 6 | 5 | 13 | 11 |
| **F→E** | 1500 | 1884 | 0,796 | 5 | 3 | 9 | 7 |

The new calculated cycle C = 67 (s), gives better results in relation to the current cycle C = 83 (s), if we compare table 3.6 with table 3.7, shows better results.

## IV. CONCLUSION

In this article we have studied the vehicular mobility at a controlled intersection, applying the Webster formula. We have determined the delay and therefore the intersection level service (LOS), we have also calculated the optimal cycle, and through the queuing theory we have compared the value of the current cycle with the optimum. We can summarize some recommendations to reduce the congestion at this point:

1- Decrease the time of the current cycle for a value between 67 (s) and 80 (s).
2- It is necessary to take into account the location of the pedestrian crossings at the accesses, in the present case, are too close to the central ring, which causescongestionfor the vehicles, in the time interval of the pedestrian green. Would be interesting to move the crosswalk away from the central ring.
3- As a solution to make mobility more sustainable, we can prohibit access to the city center (from node 'E') for vehicles, except public transport (small and large taxis, bus), to leave more space for pedestrians, which significantly reduces traffic congestionand thepollutants emissions.

As a future work we can evaluate the consequences of this result, in the next controlled intersection 'O', as illustrated in figure 2.3.

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Marwane Benhadou" Sustainable traffic circulation at controlled intersection"International Journal of Computational Engineering Research (IJCER), vol. 09, no. 2, 2019, pp 12-20