Traffic-light Cycle Coordinated by Microsimulation: a Solution to the Traffic Congestion in Palermo

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Abstract—**This article aims to highlight the results of an analysis of the traffic management carried out by the Department of Civil Engineering of the University of Palermo, through traffic microsimulation model and mathematical calculations. In this paper, we demonstrate the usefulness of a coordinated traffic light cycle in an area of Palermo with high traffic flow. To achieve this, we used microsimulation for planning traffic lights, we calculated mathematically the phases in traffic lights and we made changes in the geometry of the intersection. Although this approach is not new, we would like to emphasize the importance of the use of microsimulation models in urban planning of medium-size cities, such as Palermo, characterized by a high rate of traffic congestion.**

Keywords- microsimulation model; traffic lights.

I. INTRODUCTION

Mobility is one of the most important elements of a modern society [1] and traffic congestion has been causing many critical problems [2].

Palermo, as many cities and towns in the world, is subject to high traffic flows and their corresponding consequences in terms of air pollution, congestion, and decreased levels of safety.

A proper planning of traffic-light cycle could reduce this kind of problems, improving vehicles flow. Some of the advantages of intersection traffic lights include: homogeneous traffic flows, orderly movement of vehicular currents, reduction of the frequency of accidents [3][4][5][6].

The traffic lights planning cycle is a task often complicated by the number of traffic lights installed in the urban road network: when the nearby traffic lights operate independently, vehicles have a bumpy ride because of the ongoing stops and starts, resulting in degraded performance and increased pollution. To synchronize and coordinate systems means to link them together so as to achieve a constant rate in turning green [7]. It is therefore essential to have a proper synchronization of intersections, whose programming is most often preceded by simulations carried out by the use of microsimulation models. These are a source of immediate and continuous information on the traffic flow [8][9][10][11].

Thanks to the development of innovative software, models capable of representing the dynamic of flow conditions, which actually occurs on road infrastructure, have been created.

Depending on the level of aggregation, there are three main types of models: macroscopic models, mesoscopic models, and microscopic models.

In macroscopic models, traffic flow is defined by the rules of conduct that are a function of the interaction of vehicles with each other and with the infrastructure, and the main variables that are taken into consideration are flows, velocity and density [13]. In this type of model, the current traffic as a whole is analyzed, and not the individual vehicles in the network; therefore, these models are called "continuous". Mesoscopic models differ from macroscopic models by the fact that they consider the current traffic by dividing it into groups of vehicles, which can be, for example, the platoons that move in response to a traffic light stop. Microscopic models, or microsimulation models, differ from the two first mentioned as the smallest unit analyzed is represented by the single vehicle, which moves on the road network and interacts with the other vehicles and with the infrastructure, according to a series of parameters that depend on instantaneous velocity, acceleration, drivers behavior, and mutual distances between the vehicles themselves [13]; these models are then "discrete".

In this paper, we present a microsimulation application related to the area between piazza Don Bosco and piazza Leoni in Palermo (Figure 11), classified in the urban traffic plan as interdistrict roads because of the connection between the city center with Mondello.

Using microsimulation models, two scenarios are analyzed:

- The current scenario (with uncoordinated traffic lights cycles);
- The project scenario (with coordinated traffic light cycles).

In the following section, we describe the current scenario by providing an overview of the intersection arrangement. We also describe the scheme used for the construction of the microsimulation model: matrix origin/destination and the other variables useful for the analysis (e.g., travel times, traffic signal cycle times, etc.).

In the third section, the project scenario is described. In this scenario, differently from the present scenario, the traffic light synchronization is implemented, and we hypothesize a change at the intersection of piazza Leoni. In addition, we provide useful calculations for analysis scenario and in comparison to the present scenario (e.g., saturation flux, load index, equivalent courses, cycle traffic lights, etc.).

In the last section, we show the study results, indicating in particular the benefits in terms of travel time.

II. THE CURRENT SCENARIO

Palermo is the capital of Sicily. With 678,412 inhabitants, this city is one of the most congested in Europe, with critical areas such as intersections, where there are frequent traffic jams. Following an increase in demand for transport, due to the high number of vehicles on the infrastructure, there is a consequent deterioration of the circulation. Therefore, a reorganization of the road network is essential. The reasons for the increase in transport demand are several, such as the increase in the number of cars and the deficiencies is public transport. This leads to overloaded road networks. It is, therefore, necessary to take action and perform analysis to understand what interventions can improve the transport.

To control vehicle movement in intersections, Palermo, as any other city, uses traffic lights in order to minimize interference between moving vehicles.

The area under consideration in this paper includes two intersections in the city of Palermo, piazza Don Bosco and piazza Leoni (Figure 12). This area is congested due to the presence of sport centers in Viale del Fante (such as the stadium, the swimming pool and the race course) and the connection with Mondello; no less important is the presence of numerous lorries that cross the two intersections from via Imperatore Federico to reach highway A29 Palermo-Mazara del Vallo.

The two studied intersections are located at a distance of about 300 meters and a coordinated traffic lights system is currently absent: the two traffic light cycles are uncoordinated for duration and stage numbers.

The traffic light cycle of piazza Don Bosco has three phases articulated (Figures 1, 2 and 3) in 142 seconds (Table I), while the current traffic-light cycle in piazza Leoni has two phases (Figures 4 and 5) lasting a total of 86 seconds (Table II).

TABLE I TIME OF TRAFFIC LIGHTS CYCLE – PIAZZA DON BOSCO

Time of traffic lights cycle 142 (sec)								
Step1			Step 2			Step 3		
Green 1	Yellow 1		Green 2	Yellow 2		Green 3	Yellow 3	
63	3	2	35	3	2	29	3	2
G				Y	R			
G	Y	R						
G	Y	R				G		
R			G	Y	R			
R			G				Y	R
R						G	Y	R

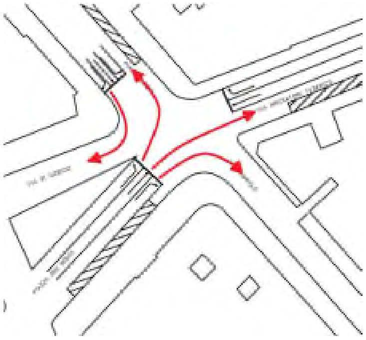

Figure 1. Step 1 in current scenario – Piazza Don Bosco

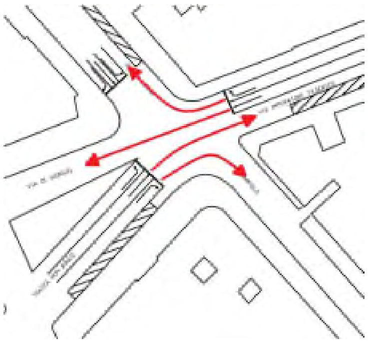

Figure 2. Step 2 in current scenario – Piazza Don Bosco

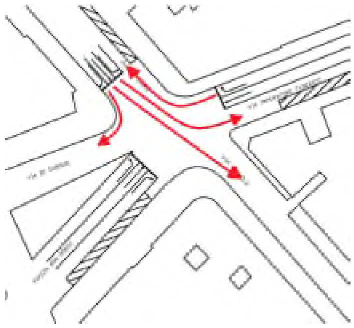

Figure 3. Step 3 in current scenario – Piazza Don Bosco

TABLE II TIME OF TRAFFIC LIGHTS CYCLE – INTERSECTION PIAZZA LEONI

Time of traffic lights cycle 86 (sec)					
Step 1			Step 2		
Green 1	Yellow 1		Green 2	Yellow 2	
41	4	2	33	4	2
G	Y	R			
R			G	Y	R
G					

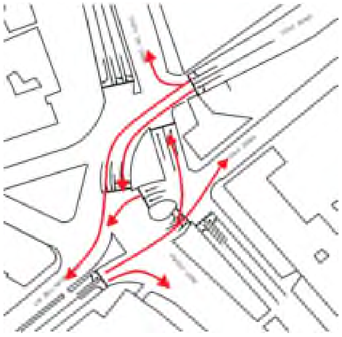

Figure 4. Step 1 in current scenario – Piazza Leoni

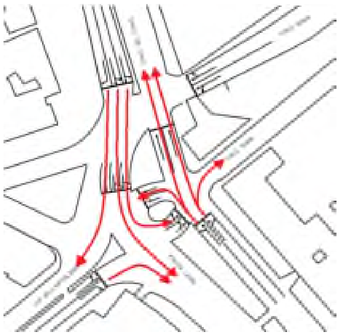

Figure 5. Step 2 in current scenario – Piazza Leoni

From the survey of the traffic flow in each intersection, which was done in December 2013 at 8:00/9:00, 13:00/14:00, 18:00/19:00, we were able to obtain the origin-destination matrix of the whole network for each class of traffic (cars, buses, motorcycles and heavy vehicles). In addition to the vehicles, we have also considered pedestrian flows.

The comparison between the measurements in different bands showed that the traffic flows do not undergo significant changes during the day and it is therefore justified to use a fixed-cycle.

For the analysis through microsimulation models, we consider the time slot 8:00/ 9:00 am.

The maximum traveling speed was estimated through a survey with GPS in a car, carried out over a period of the day with low traffic flows, with data logging interval of 5 seconds. The GPS survey was carried out along 24 routes, connecting each source to each destination. We used a GPS with accuracy of 5 meters and data storage interval equal to 1 second.

The collected data were processed with the aid of the QuantumGIS [14]. Knowing the time of storage of each point we obtain, by the difference, the travel time.

The travel times calculated thanks to the GPS survey were compared to the minimum, average and maximum time values obtained from the simulations, verifying the condition (1).

$$t_{min} \leqslant t_{GPS} \leqslant t_{max} \qquad (1)$$

III. PROJECT SCENARIO

The synchronization of the plant was carried out considering as a priority the traffic coming from the access of viale del Fante and that along the stretch between the two junctions.

We decided to set up a three cycle phases in piazza Leoni (Figures 6, 7 and 8), so we removed two traffic lights currently present in the central island of the same intersection. We retained only the traffic lights that control the left-turn vehicles from viale del Fante, allowing thus in one step the left turn for users coming from viale Diana and via dell'Artigliere and preventing access from piazza Leoni.

The origin-destination matrix of the project scenario was then modified with respect to the real scenario only with respect to the vehicle coming from the intersection of Piazza Don Bosco with destination via dell'Artigliere.

In the phase plane of piazza Don Bosco (Figures 9, 10 and 11), we considered a different sequence of the three phases, giving the green light the same time to the current traffic with similar index in both intersections.

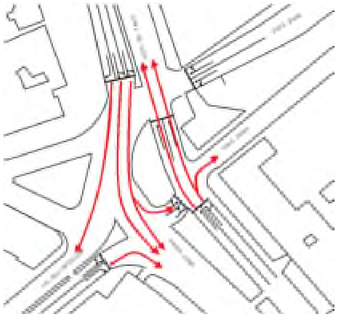

Figure 6. Step 1 in project scenario – Piazza Leoni

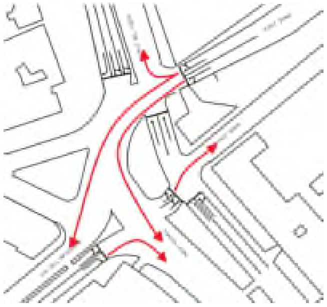

Figure 7. Step 2 in project scenario – Piazza Leoni

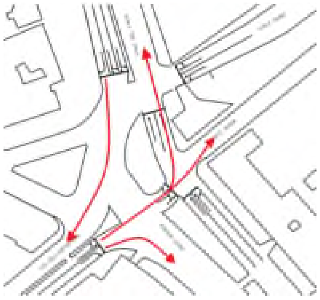

Figure 8. Step 3 in project scenario – Piazza Leoni

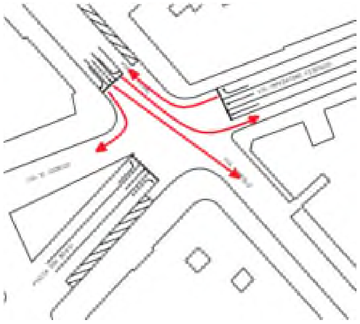

Figure 9. Step 1 in project scenario – Piazza Don Bosco

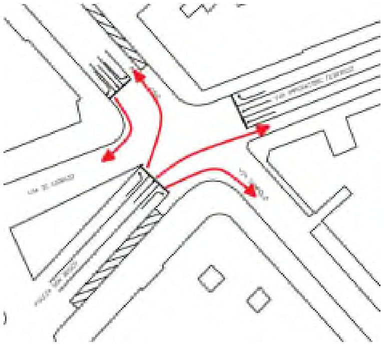

Figure 10. Step 2 in project scenario – Piazza Don Bosco

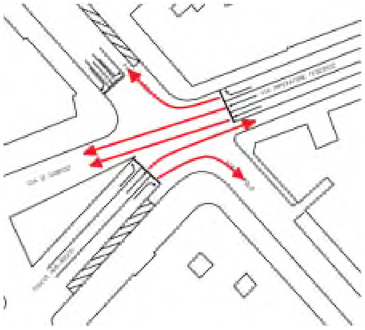

Figure 11. Step 3 in project scenario – Piazza Don Bosco

It was also useful to add an additional lane to the crossing of via Imperatore Federico, whereby the load index of the lane group coming from access lanes in question has decreased. This change was possible because via Di Giorgio is large enough to accommodate two lanes, allowing for an increased capacity of the arc in question.

Regarding the traffic lights of piazza Leoni, we adopted, as a first step, the crossing from viale del Fante, synchronized with the first phase of piazza Don Bosco, which involves crossing and turning from the access piazza Leoni in order to get the green wave.

For the calculation of the traffic-light cycle, we identified the groups of critical lanes and the respective load indices, and we proceeded to the calculation of the minimum cycle.

Load indices, defined as the ratio between the flow rate and the saturation flow, were calculated after determining these two quantities.

The saturation flow was calculated using the relation proposed from HCM (Highway Capacity Manual) [12] as in (2).

$$FS = FS_0 * N * f_b * f_{tp} * f_i * f_p * f_B * f_a * f_u * f_D * f_S * f_{PD} * f_{PS} \qquad (2)$$

where:

- FS_0 is saturation flux under optimal conditions;
- N is the lanes number;
- $f_b$is coefficient of the lane width;
- f_{tp} is coefficient of heavy vehicles;
- f_i is slope coefficient;
- f_p is social activities coefficient;
- f_B is a coefficient that take into account the presence of bus stops;
- f_a is area coefficient;
- f_u is lane use coefficient;
- f_D is right turns coefficient;
- f_S is left turns coefficient;
- f_{PD}e f_{PS} are pedestrian coefficients.

The course equivalents have been deduced from the values of different traffic flows for the four categories of vehicles, by multiplying the coefficients relating to the type in question. The coefficients are:

- 1 for passenger cars;
- 1.75 for heavy vehicles;
- 2.25 for buses;
- 2.5 tram;
- 0.33 for motorcycles;
- 0.2 for bicycles.

This way, we obtained all the load indices for each group of lanes and, for the purposes of calculating the traffic-light cycle, we considered the highest values for each of the three phases, having determined the plane of the stages shown in the previous figures.

The cycle (3) then applies:

$$C_{min} = \frac{\sum_{i=1}^{n}(P_i+TR_i)}{1-(\sum_{i=1}^{n}\gamma_i)} = 133\ sec \qquad (3)$$

where:

- *i* is traffic-light phase;
- *P* is total time waster;
- *TR* is actual red light duration;
- γ_i is equal load capacity index, with the highest value in the i-th stage.

We calculated TR (4) for each of the three phases based on the length of the trajectory of the restrictive vehicular current:

$$TR_i = t_{pr} + \frac{S_f+D+d}{v_v} - G = 3\ sec \qquad (4)$$

where:

- t_{pr} is perception and reaction time;
- S_f is braking distance;
- D is trajectory length;
- d is average length of vehicles;
- v_v is speed vehicles.

The time yellow G is assumed to be equal to 4 seconds, as in urban areas. The braking distance was calculated considering the arrival rate imposed by the limits of the law.

We obtained a minimum cycle of 133 seconds. We decided not to calculate the optimal cycle because it would lead to even higher values. Then, deciding to adopt a three-phase cycle of 133 seconds, we determined green times (5) effective for each phase:

$$VE_i = \left(\frac{Q_i}{FS_i}\right) * C \qquad (5)$$

where:

- Q is the incoming flow;
- C is the entire cycle length

The time thus obtained are:

- VE_1 = 40 seconds;
- VE_2 = 42 seconds;
- VE_3 = 30 seconds.

The times for green (6) and red (7) were found using the following two relations:

$$V_i = VE_i + P_i - G_i \qquad (6)$$

$$R_i = C - (V_i + G_i) \qquad (7)$$

Table III shows the schematic of the traffic-light cycle of the project. As can be seen from the table, some maneuvers are permitted in stages, not presenting points of conflict with other simultaneous operations. Specifically, it is allowed to turn right on Viale del Fante in the first and in the third phase, as well as the right turn from via Imperatore Federico. The crossing and turning right from the access of piazza Don Bosco have been retained in the second and third stages.

TABLE III TIME OF TRAFFIC LIGHTS CYCLE – GLOBAL AREA

<table>
<tr><th colspan="9">Time of traffic lights cycle 133 (sec)</th></tr>
<tr><th colspan="3">Step 1</th><th colspan="3">Step 2</th><th colspan="3">Step 3</th></tr>
<tr><th>Green 1</th><th colspan="2">Yellow 1</th><th>Green 2</th><th colspan="2">Yellow 2</th><th>Green 3</th><th colspan="2">Yellow 3</th></tr>
<tr><td>40</td><td>4</td><td>3</td><td>42</td><td>4</td><td>3</td><td>30</td><td>4</td><td>3</td></tr>
<tr><td colspan="4">G</td><td>Y</td><td colspan="4">R</td></tr>
<tr><td>G</td><td>Y</td><td colspan="7">R</td></tr>
<tr><td>G</td><td>Y</td><td colspan="4">R</td><td colspan="3">G</td></tr>
<tr><td colspan="3">R</td><td>G</td><td>Y</td><td colspan="4">R</td></tr>
<tr><td colspan="3">R</td><td colspan="4">G</td><td>Y</td><td>R</td></tr>
<tr><td colspan="6">R</td><td>G</td><td>Y</td><td>R</td></tr>
<tr><td colspan="9">G</td></tr>
</table>

Finally, we determined the offset time between the cycles of the two intersections, so that the vehicles of the current priority can continue beyond the first traffic lights avoiding further stops. Knowing that the distance between the stop lines of the current priority is equal to 350 meters, advising the maintenance of a constant speed equal to 40 km/h, we calculated an offset of 32 seconds, in this way we favored the current flowing in the path from viale del Fante at the intersection of piazza Don Bosco.

We completed the changes to the project network via Cube Dynasim and we carried out simulations by collecting data from Data Collector always placed in the same sections, in order to make a comparison between the current situation and that of the project. The data were compared for the minimum, average, and maximum travel time, with particular attention to the average time relative to both scenarios.

IV. CONCLUSIONS

The changes made to the current scenario were geometric and logical, having changed the origin-destination matrix, the distribution of the lanes, especially, the traffic-light cycle. These variations have been applied on the microsimulation models, in order to verify an improvement in the conditions of the current outflow with propriety and without having an excessive deterioration of the secondary flows.

The geometric changes have therefore provided the addition of a lane of accumulation for the crossing from via Imperatore Federico, whose length has been set equal to 80 meters, with consequent removal of the area for stopping; the elimination of left turn onto via dell'Artigliere for vehicles coming from piazza Leoni.

When comparing the simulated times with the current scenario, there was a reduction of throughput times for all destinations with origin viale del Fante, via Imperatore Federico, piazza Don Bosco, which are the paths along the streets of interdistrict.

Variation Journey Times = (Time of Scenario Current / Time of Project Scenario) -1 *(8)*

In particular, the paths via Imperatore Federico, via del Fante, and via Sampolo (Table IV) we obtained, as in (8). We also obtained a reduction in average travel times by 20% and 10% to viale del Fante and via Di Giorgio, and via Artigliere and via Diana by just over 7 %. This confirms that coordination reduces the average travel times and, as you can see, the largest decreases for access viale del Fante take place for couples origin-destination connecting the two intersections.

For paths with origin piazza Don Bosco, there were reductions in the average travel time varying from 8 to 38% , with the major reduction happening for maneuvers and left turn crossing into the intersection itself.

The greatest reduction was for the crossing of via Imperatore Federico, where the addition of an extra lane produced a reduction in the average travel time by 55 %, from 134 seconds to just 60 seconds.

In order to demonstrate the utility of using a traffic-light cycle coordinated by microsimulation to reduce the problem of congestion in Palermo, we studied an alternative scenario than the current one. In particular, we have changed the distribution of the lanes and we have determined a traffic-light cycle common to both intersections.

We have temporally spaced so that the traffic-light cycle vehicles of current priority, surpassing the first stop line and maintaining a constant predetermined speed, can continue along the route without making further stops.

By performing the simulation scenario of the project we have observed an improvement in terms of average travel times along the routes identified as a priority, which leads us to confirm the validity of the instrument microsimulation which supports the design of alternative solutions.

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TABLE IV VARIATION JOURNEY TIMES

Time	t_{med}		t_{med}		t_{med}		t_{med}		t_{med}		t_{med}	
	t_{max}	t_{min}	t_{max}	t_{min}	t_{max}	t_{min}	t_{max}	t_{min}	t_{max}	t_{min}	t_{max}	t_{min}
O/D	*Via dell’Artigliere*		*Viale Diana*		*Via Di Giorgio*		*Via del Fante*		*Via Imperatore Federico*		*Via Sampolo*	
Via dell’Artigliere	/		113,64%		31,48%		32,00%		-15,28%		-20,25%	
			-10,61%	0,00%	17,65%	17,24%	-32,96%	-40,74%	-24,64%	28,13%	-30,80%	11,43%
Viale Diana	22,64%		/		-4,39%		17,31%		29,15%		17,07%	
	-4,00%	44,57%			-20,38%	20,77%	2,71%	55,13%	12,76%	76,00%	-6,08%	30,06%
Piazza Don Bosco	/		-12,38%		/		-8,33%		-38,24%		-29,03%	
			-18,60%	16,13%			-21,29%	23,33%	-23,17%	75,00%	-28,41%	166,67%
Via del Fante	-7,45%		-6,71%		-9,88%		/		-20,79%		-19,62%	
	8,14%	-56,00%	1,57%	27,06%	-14,53%	30,00%			-16,78%	-52,38%	-26,78%	-51,00%
Via Imperatore Federico	/		-15,22%		-55,22%		-7,77%		/		/	
			-13,08%	0,00%	-48,93%	-72,09%	-34,60%	-2,33%				

Figure 12. Map of the study area