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ORIGINAL ARTICLE

DEVELOPMENT OF A METHODOLOGY TO STUDY PARKING DEMAND IN TANGIER CITY

| Marwane Benhadou |

Abdelmalek Essaadi University | Laboratory of innovative technology | Tangier | Morocco | mrwbenhaddou@gmail.com |

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ABSTRACT

Background: The increasingly scarce spaces in urban center, with the progressive growth of the car fleet, insist on more effective and efficient parking management. Which it has a direct impact in reducing congestion, improving urban circulation and life quality of citizens. Therefore, a simple parking management does not lead to a satisfactory result, it is not easy to analyze parking demand, this requires an intensive field work to quantify the level of demand, even more for large study area**. Objectives**: In this paper we will study the parking policy in the center of Tangier city. We analyze the study area, for more efficient data collection, we use operational research algorithms, analyzing both on-street and parking lots (off-street). The objective is determining the blue zone impact on the parking demand and develops parking state indicators. **Methods**: To carry out the process of data collection we model the study area as a graph, to identify each section, and then we use operational research algorithms (CPA, Chinese Postman Algorithm) to facilitate and optimize the counting of cars on public roads. **Results:** Data collection refers to the number of places available on the public road, on-street and parking lots in each segment of the graph, during peak hours of the day (9h, 13h, 17h, 19h). The result will be the level of demand in each section, and the level of parking illegalities. A table summarizes the indicators related to parking, offer-demand of places, the rate and type of illegalities. Also development of indicators summarized in tables show a comparison between the demand state of parking before and after applying bleu zone. **Conclusions:** The use of an algorithm to optimize data collection, facilitates the field work and spent less energy and time. The results show a high demand for parking before using blue zones. The first experience in Tangier city using blue zone, shows positive results in decreasing demand on parking, increase rotation rate, leaves more places to park and the demand is more rational.

Keywords: *Parking policies, Chinese Postman Algorithm, Mobility in Tangier*.

1. INTRODUCTION

Sustainability is at the heart of mobility strategy, it is a key challenge, and it is essential therefore to know how it can be measured. What strategies are available to improve the sustainability of mobility? In literature, there exist several attempts to change mobility and make it more sustainable [1].

Parking management is a powerful weapon with which cities can exert influence over transport. By managing the offer, design and price of parking spaces, cities can exert a high level of control over the traffic flow. In the past, municipalities expand the parking offer with the sole purpose of attracting more cars. Current parking policies adopt a more balanced vision, including social and environmental goals to improve the quality of life in cities [2].

European cities apply new parking policies in order to make mobility more sustainable, for example, in Vienna uses parking management strategically in order to control traffic demand and meet sustainable objectives, including reducing air pollution [3]. There are several cities that aim to reduce the total supply of parking, including Copenhagen, Zurich or Brussels [4,5]. Amsterdam has adopted a highly technological approach in its transport management, set parking fees based on emissions [5].

Also, researchers have studied the different parking policies as a key to sustainable mobility in cities [6], as example in [7], the authors present a parking search model based on the behavioural modeling, using the Expected Maximum Utility (EMU). Another approach, directed by the expert in parking based on demand, Donald Shoup, analyzes the different parking policies, as off-street parking and its repercussion on traffic congestion, pollution and charges market prices to manage on-street parking [8-9-10-11]. Others analyze the consequences on the driver behavior, developing a model for congestion interaction in downtown between cars in transit and cars cruising for parking [12]. Parking analysis requires effort and a certain skill, such as field analysis, unified work of many sectors, among others [13]. In another case, the authors have studied the relationship between demand for parking and socio-economic data of cities, applying Multiple Linear Regression [14]. Most of the studies focus on the effects of parking on travel demand, like in [15] a Logit model was adapted to model parking choice, or also develop a relation between demand for on-street parking and parking pricing [16], or limiting the amount of parking places in cities, like the study done in [17] where researchers have developed an intelligent parking guidance system, using multi agent spatially explicit model for parking search. The biggest challenge in the parking analysis is the data collection related to the demand [18-19], the authors has developed a methodology for data collection, related with, parking capacity, average occupancy rate and average parking duration Most studies are interested in the impact of parking policies on economy, mobility and traffic flow [20-21-22-23-24].

In the case of carrying out a survey of the studied area, it is recommended for a more precise study, use manual counting to determine the exact number of places, also their location, this method is most used by municipalities [25].

To carry out the process of data collection we will use a methodology, based on operational research algorithms to facilitate and optimize cars counting on public roads.
The objective will be to study the parking demand before using limited areas with parking time (blue zone, as depicted in figure 6) and after using this mechanism of control.

2. MATERIALS AND METHODS

2.1 Description of the studied area:

Tangier-Tetouan region (North of Morocco), with 2.8 Million populations, one of the largest densities in the kingdom of Morocco, 235 Hab/ Km2 [26]. The largest city in north of Morocco, Tangier, which is set to receive an ambitious slate of projects between 2010 and 2017. Tangier population has evolved from 762583 in 2004 to 1160302 in 2014 [26], 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, Tangier's economy is the third biggest of all Moroccan cities.

All these factors will contribute to an increase in traffic congestion, especially in the center of Tangier city, where pedestrians are concentrated and also is a passage-point of most vehicles.

The traffic management started in 2001, when Tangier municipality debuted with a parking management program TANGER PARK, but this program has failed, and they have canceled the contract in 2010 [27]. Currently the new company hired by the municipality, trend to construct underground parking to leave more space on the surface, also introduce a new parking management on public roads through areas limited by time [28, 29].

In this studied area, we locate many centers of attraction and generators of movement, there are shopping centers (generation of travel), schools that generate high pedestrian and vehicular mobility during peak hours, hospitals, cafes, restaurants, and also a residential area, as depicted in figure 1.

2.2 Modeling the studied area:

To facilitate the process of data collection, we convert the studied area into an undirected graph [30, 31], where the vertex corresponds to the intersection (in this case identified by letters) and edges are the street sections between nodes, as shown in figure 1. The digitalization divides the area into zones that should be manageable for on-site work. So to find out the number of parked cars (inventory), you have to go through all the streets and count the vehicles parked on the public road (on-street parking) and in the parking lot (off-street parking).

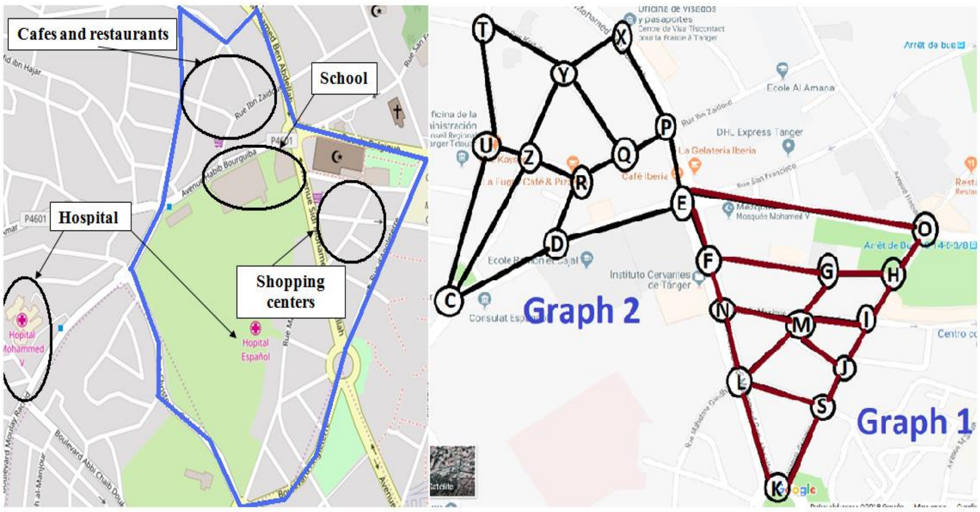

Figure 1: The figure presents the studied area and graph model.

2.3 Data collection:

Data collection refers to the number of places available on the public road, both on the sidewalks of the street and parking lots as depicted in figure 2, during peak hours of the day (9h, 13h, 17h, 19h).

As you can verify, the studied area is large, and the streets are not arranged in order to organize the process of data collection, consequently the graph can be divided into two subgraphs, in that way we can facilitate the work, each graph separately (graph 2 and graph 1), as you can see in figure 1.

Now, the idea is, how we can go through all the streets without repeating the work, otherwise, how can we go through all the edges only once (traversable graph) ?

If this condition is verified, the graph will be Eulerian [31], and the path is Eulerian cycle.

In this case, the vertexes must be even, this means, the number of edges connected to the node must be even. For example, as illustrated in the figure 1, the graph on the right, the nodes G, M, H, I, J, S, N and F, they are odd.

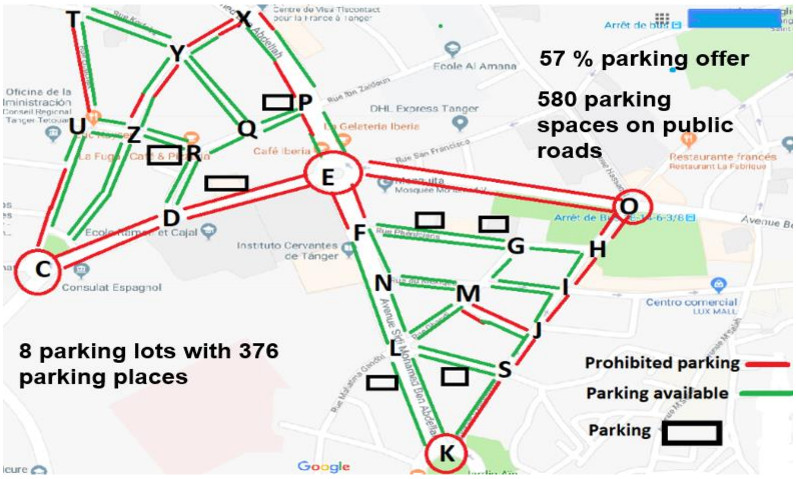

Figure 2: The figure show the parking situation in the studied area.

Therefore, we transform that graph to a Eulerian graph, using CPA, the Chinese Postman Algorithm [31,32]. In the CPA algorithm, we use 3 algorithms to reach the optimal result, first we apply Floyd or Dijkstra algorithm to find the shortest path between each node and the other nodes, in the second step, we identify the minimum weight among the set of nodes using the Hungarian algorithm, and in the last step, we use Hierholzer algorithm to find the Eulerian path. You can find out in Algorithm I:

<u>Algorithm I</u> CPA to define the optimal path of the Chinese Postman Problem in each graph

1-V set of odd vertex
2-For each pair of vertex **(i, j) ∈ V**
    Floyd Algorithm=Find the shortest path **P= d(i,j)** in **G**
        For k=1→n
            For i=1→n
                For j=1→n
                    C(i,j)=min(c(i,j),c(i,k)+c(k,j))
                    If c(i,j) > c(i,k)+c(k,j)
                        S(i,j)=k
Make a new graph **N** with the vertexes of **V.**
For each edge **s** of **N**
    Assign to the edge **s** the length **d (i, j)**
3-Hungarian algorithm
Find the minimum total weight **M** in **N**
For each edge **s** in **M**
    P→d(i,j)
    For each edge **l** of **P**, add to the graph **G** a copy of **l** with its length.
4-Let **G→E** an Eulerian graph formed by adding to **G** the duplicate edges.
5-Hierholzer's Algorithm
Find a Eulerian Cycle **W.**

Route=null
V="Node set vector"
I="cost matrix"
A="multiplicities matrix"
        While (some element of I ≠0)
                vertex=not an isolated node by eliminating the edges used in route
                Route1=Null
                While (vertex, not an isolated node)
                        'we found k so that A[vertex,k]≠0'
                        Route1=(route1,k)
                        Vertex=k
                        A[vertex,k]=M[vertex,k]-1
                        A[k,vertex]=A[k,vertex]-1
                Route="we add route to route1"

The Eulerian Cycle W corresponds to the optimal path of the Chinese Postman Problem. We apply the CPA in each graph separately, as illustrated in fig 1. We discuss the result in the following section.

3. RESULTS AND DISCUSION

3.1 Optimum cycle tour W:

To transform our graph, we apply steps 1, 2 and 3 of the CPA algorithm. The number between nodes indicates distance, calculated through google maps application. The results is shown in figure 3, we add fictitious nodes, this procedure means, repeat the data collection twice in that segment (once by the side of the same street).

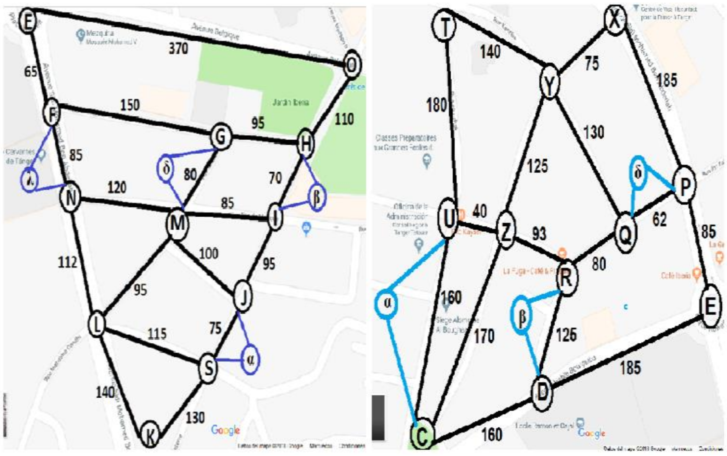

Figure 3: g The figure presents the graph transformation.

Then, we apply Hierholzer's algorithm, to determine the optimum cycle tour, which accepts as input an adjacency matrix of each graph and number of nodes, as depicted in figure 4 (for example, in graph 2 they are 14 nodes, graph1, 16 nodes).

14														
	U	T	Y	X	α	Z	R	Q	P	C	D	β	δ	E
U	0	1	0	0	1	1	0	0	0	1	0	0	0	0
T	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Y	0	1	0	1	0	0	0	0	0	0	0	0	0	0
X	0	0	1	0	0	0	0	0	1	0	0	0	0	0
α	1	0	0	0	0	0	0	0	0	1	0	0	0	0
Z	1	0	1	0	0	0	1	0	0	1	0	0	0	0
R	0	0	0	0	0	1	0	1	0	0	1	1	0	0
Q	0	0	1	0	0	0	1	0	1	0	0	0	1	0
P	0	0	0	1	0	0	0	1	0	0	0	0	1	1
C	1	0	0	0	1	1	0	0	0	0	1	0	0	0
D	0	0	0	0	0	0	1	0	0	1	0	1	0	1
β	0	0	0	0	0	0	1	0	0	0	1	0	0	0
δ	0	0	0	0	0	0	0	1	1	0	0	0	0	0
E	0	0	0	0	0	0	0	0	1	0	1	0	0	0

16																
	J	α	S	K	L	N	M	I	β	F	G	λ	δ	H	O	E
J	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0
α	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
S	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
K	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
L	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
N	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0
M	1	0	0	0	1	1	0	1	0	0	1	1	0	0	0	0
I	1	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0
β	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
F	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1
G	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0
λ	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
δ	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
H	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
E	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0

Figure 4: The figure show the adjacency matrix of each graph.

The result of algorithm I execution, is the optimal tour through all the streets under the minimum restriction (repeat twice the passage through a street), the number on the edges indicates the order to be traversed the graph, as illustrated in figure 5.

Graph 1:

J-M-G-δ-M-N-F-E-O-H-β-I-M-L-S-K-L-N-λ-F-G-H-I-J-S-ɑ
Graph 2:
U-Z-R-D-β-R-Q-P-δ-Q-Y-X-P-E-D-C-U-ɑ-C-Z-Y-T-U

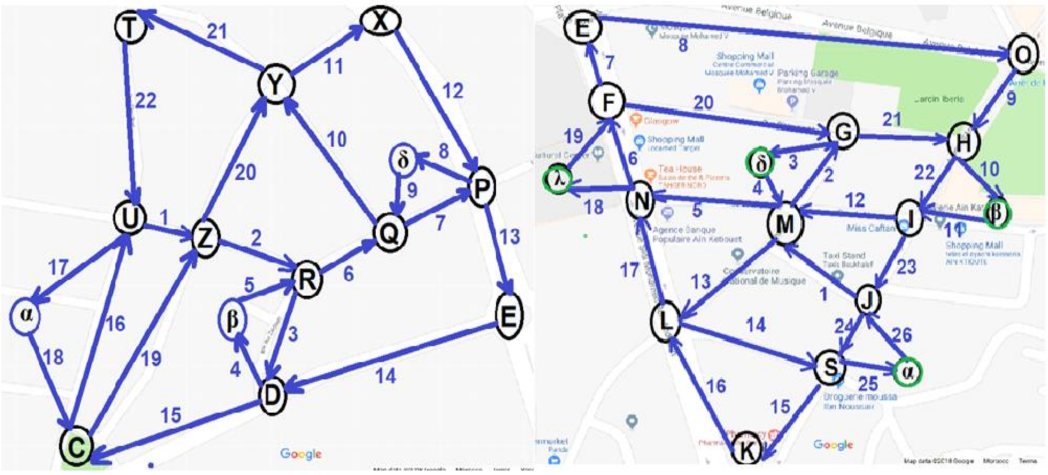

Figure 5: The figure demonstrate the optimum cycle tour W in graph 2 and 1 respectively.

After identifying the optimal circuit of each graph, we proceed to the data collection in each one separately. The data collection is done throughout the day during peak hour in a week. We repeat the same process during 4 months and then we take the average value of the measurements. We will develop indicators relating to parking demand in each graph separately.

3.2 Parking indicators

An indicator it's a variable with characteristics of quality, quantity and time, used directly or indirectly to measure changes in a situation and appreciate the progress. It also provides a basis to develop adequate plans for improvement [33]. In our case it will be a measure of parking demand in the study area and to compare two situations: the demand for parking before using blue zone and after using this mechanism in some streets as indicated in the figure 6. The study will be for each region separately.

Graph 2:

we resume the indicators in table 1:

This table summarizes on-street parking indicators, the offer-demand of places and rate of illegality [34, 35].
The parking illegality can be calculated using equation 1:

$$I_{parking} = \frac{X}{Y+X} \qquad (1)$$

Where,

X: numbers of illegal places,
Y: number of places offered,

Table 1: The table presents the on-street parking indicators for graph 2.

Avenue	Origin node	Destination node	Occupation %	Illegality rate	Parking offer
Habib Bourguiba	C	E	0	100	0
El ouchak	T	C	86	7	56
Grenade	C	X	90	0	64
Sidi Mohamed Ben Abdellah	E	X	107	40	37
Qortoba	T	Q	80	25	18
Ibn Zaydoun	D	P	97	16	58
Casablanca	U	R	75	0	17
Total			89,16	26,86	250

There is a high occupation level in the public roads (on-street parking) with 89,16 %, Sidi Mohamed Ben Abdellah avenue is the most occupied with 107 %, it's a principal avenue, also Ibn Zaydoun avenue with 97 %. In what refers to the illegality, Hbib Bourguiba avenue expresses a high level of parking illegality, is due to the school, also this avenue expresses a high vehicles flow, in peak hours, that coincides with school departure time, which causes a difficult circulation.

The illegality rate is 27%, and it would be interesting to study types of illegalities. The parking illegalities in the studied area are divided in pedestrian sidewalks, double parking, pedestrian crossing, loading/unloading and park in a prohibited place as intersections and prohibited parking. The cars that park at the intersection 'E', as depicted in figure 2, is due to the departure time of students from school, as well as the avenues surrounding the school which is the highest level of illegality 61 %.as reflected in table 2:

Table 2: The table presents the types of illegalities in graph 2.

Pedestrian sidewalks %	Double parking %	Pedestrian crossing %	Loading/ Unloading %	Illegal parking %	
				61	
7	9	6	17	Intersection	Prohibited parking
				30	70

I have also studied the level of demand in parking lots (off-street parking), as illustrate in figure 2, there are 4 parking lot in graph 2. As reflected in table 3, the indicators determine the parking lot occupation, the data collection is done during the peak hours.

Table 3: The table presents the parking lot occupation (off-street parking) in graph 2.

Avenue	Origin node	Destination node	Occupation %				Parking offer
			9h	13h	17h	19h	
Hbib Bourguiba	E	D	68	100	88	70	50
Casablanca	Z	R	25,7	71,4	51,4	80	35
Ibn Zaydoun	Q	P	62,5	95	90	52,5	40
Ibn Zaydoun	R	Q	61,5	73	65,4	92,3	26
Total			62				151
			46	73	62,7	65	

The parking located in Hbib Bourguiba Avenue expresses a high level of occupation 81.5% and this is due to departure/enters time of schools. The parking are more occupied afternoon and evening, in general, the demand is not high with an occupation of 62%.

Graph 1:

We follow the same process that we have applied in graph 2. We resume the indicators related with parking demand in table 4.

This table resumes the indicators related to on-street parking, the offer of places, occupation in the avenues that constitute the graph and rate of illegality.

Table 4: The table presents the on-street public parking indicators in graph 1.

Avenue	Origin node	Destination node	Occupation %	Illegality rate	Parking offer
Mhatma Ghandi	L	G	90,45	9	55
Les Pheniciens	F	H	94	15,44	67
Angleterre	H	K	91	8,05	53
Mexique	N	I	97,63	6,47	74
Sidi Mohamed Ben Abdellah	E	K	100,47	21,07	81
Total			95	15	330

All the avenues express a high level of occupation 95 %, Sidi Mohamed Ben Abdellah avenue express a high rate of illegality, due to the schools, cafes and restaurants, this area also gives access to shopping centers, so there is a great demand for mobility.

As well, we defined types of illegalities indicators; we resume the results in table 5:

Table 5: The table presents the types of illegalities, graph 1.

Pedestrian sidewalks %	Double parking %	Pedestrian crossing %	Loading/Unloading %
40	25	16	19

An illegality ratio of 15%, the parking illegalities are divided in, pedestrian sidewalks with 40 % the highest value, double parking 25%, pedestrian crossing 16% and loading/unloading 19%.

The illegality rate in this region is lower (15%) in comparison with graph 2 (27%). This difference is due to the parking on 'Hbib Bourguiba' avenue (between nodes C and E) in the time of entrance/exit of students, in the hourly interval between 13h and 14h30. In regards to the parking occupation in the study area (graph 1), as they appear in the figure 2, there are 4 public parking lots (off-street parking), 2 of them with fixed price/hour in avenue 'Les Pheniciens' between nodes F and H, the results are reflected in table 6.

Table 6: The table presents the parking lots occupation.

Avenue	Origin node	Destination node	Occupation %				Parking offer
			9h	13h	17h	19h	
Mhatma Ghandi	L	S	66	55	83	70	18
Les pheniciens	F	G	23	60	76	87	30
Sidi Mohamed Ben Abdellah	L	K	48	60	76	72	25
Les pheniciens	G	H	46	84	56	90	50
Total			66				123
			46	65	73	80	

The parking located in 'Mhatma Ghandi' avenue expresses 69% of level occupation, 'les Pheniciens' avenue (underground parking garage) between nodes G and H with 70% of the time are busy, between F and G 61,5%, 'Sidi Mohamed Ben Abdellah' avenue with 64% level of occupation. The parking with fixed price/hour (in the 'Pheniciens' avenue) are less occupied then the others, in general, the demand is not high, with an occupation of 66%. In summary mode of the whole study area (graph 1 and 2), we resume the results in table 7.

Table 7: The table presents the parking demand and illegalities indicators through the studied area.

On-street parking occupation %	Illegalities %	Parking lot occupation %
92	21	64

On-street parking demand is high than the parking lots, drivers prefer on-street parking, with 21% ratio of illegalities.

Now in the second case, we study the parking demand after using blue zone limitation park with 3,5 DH/hour, in some streets, as illustrate in figure 6, this region corresponds to the graph 1. We repeat the process of data collection in this region to compare the effect of regularizing parking.

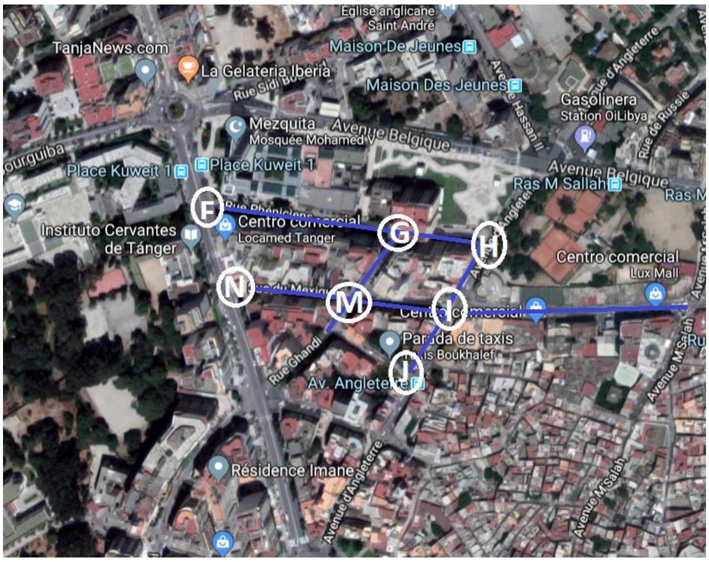

Figure 6: The figure demonstrated the new distribution of bleu zone in the studied area

The result of data collection after introducing the parking control system is summarized in table 8:

Table 8: The table presents the level of occupation and illegality rate.

Avenue	Origin node	Destination node	Occupation %	Illegality rate	Parking offer
Les Pheniciens	F	G	64	2	50
Les Pheniciens	G	H	72	0	17
Mexique	N	M	68	0	37
Mexique	M	I	78	1	37
Mhatma Ghandi	G	M	32	0	15
Mhatma Ghandi	L	M	98	0	40

If we compare table 8 with table 4, the result is represented in figure 7, shows that the distribution and occupation demand have significantly decreased after applying the limitation of parking time under the restriction of paying 3.5 Dirham/hour, this has many advantages: the rate of rotation is high therefore it is easier to find a parking place, less congestion and the level of parking illegality has dropped significantly.

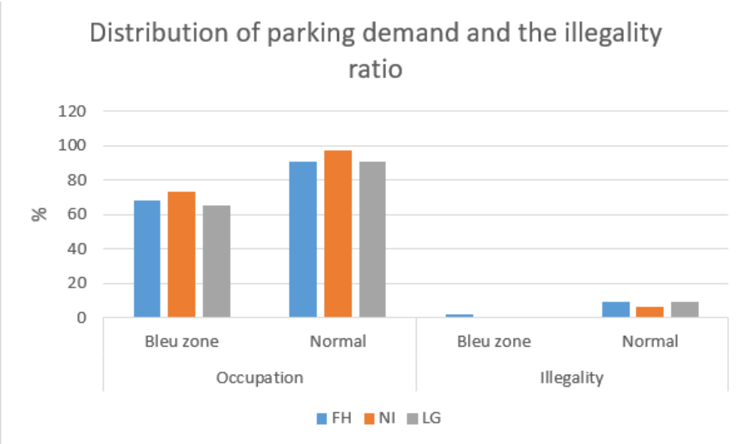

Figure 7: The figure demonstrated the parking demand and illegality ratio before and after apply bleu zone

According to the figure 7, the new control system shows a good result in relation to the occupation of places on public roads, now you can find parking places more easily and therefore the affirmation of Donald Shoup is verified, 'the high cost of free parking', now there are more places to park, and the parking search time is also reduced.

4. CONCLUSION

Many cities, are taking cautious measures to limit congestion. For example, by requiring a fee for everyone who drives into the urban center, cities can reduce the number of vehicles circulating and, at the same time, generate money, which can be invested in sustainable transport. A decrease in traffic volume has a definite impact on the levels of air pollution. The spaces for parking occupy a significant part of the valuable space of an urban center. In addition, these vehicles are only used for a short time, remaining parked up to almost 20 hours a day. Above all, cars reduce the quality of life in cities, both with the space they use and with their emissions.

In this article we have studied the parking in downtown of Tangier, this study is based on the data collection related to the parking demand. To facilitate this process, we have first applied the Chinese Postman Algorithm, to find out the Eulerian path in each graph and then we take the data in peak hours, related to the cars parked both the side of the street (on-street parking) and in the parking lot (off-street parking). The results shows a high parking illegality rate, in addition the on-street parking demand is highest than the off-street parking. Also the control mechanism introduced has shown a good result.
As a future work, we can organize the same study in summer between June and September, when the demand is higher, and check again the comparison between the two cases.

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