Article

Spatial Analysis of Curb-park Violations and Their Relationship with Points of Interest: A Case Study of Tehran, Iran

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Abstract: Car parking is a challenging part of urban transportation and the traffic violations around it cause many problems for citizens. Studies have shown that there is a direct relationship between vehicle parking violations and urban places. In this study, we investigated the spatial distribution of vehicle violations in a region of Tehran, Iran that is suffering from a heavy traffic load and heavily polluted air. Although two dissimilar urban segregations in the north and south of the study area, in both of the areas, about 70% of all curb parks are legal, while the remaining are illegal. However, our analysis indicates a dissimilar pattern of car parking violations. Also, spatial analysis reveals a direct relationship between some POIs and the occurrence of car park violations. For example, the number of vehicle park violation around the hospitals is more than the average of the study area. However, the number of park violations around the universities is less than the average. Our results also show that POIs have an impact radius that leads to violations occurring in that area. For example, the influence range of a hospital on the creation of car park violations was estimated at 125 meters. Our presented approach along with the discussed findings along with conclusions can be useful to a large range of stakeholders including urban planner, traffic police departments, local municipalities, law enforcement agencies, and environmentalists to have a better perspective of infrastructure planning.

Keywords: vehicle park violations; POI; urban safety; urban healthy living; parking prediction

1. Introduction

Since the advent of motor vehicles, providing places for parking in cities has been an important issue that should be considered in urban planning and management. In fact, every city trip ends at a park on the street or a parking lot. Therefore, park on the street is an important part of a city's transport system. Box [1] suggests that curb-parks should not be allowed next to main streets or at least during rush hours, and only on the adjacent streets where there is the possibility of parking. However, some urban and transportation planners believe that the curb-park is part of new urbanization and the value of land in the urban environment significantly increases the possibility of parking alongside it [2]. Nevertheless, in recent years, due to the growth and development of urbanization, unauthorized, chaotic, and temporary parks of cars along the streets, especially in large cities, has increased the traffic, barriers for pedestrians and drivers which violates traffic laws.

Increasing the marginal park will reduce the street width and indirectly slower traffic [3, 4]. Besides, curb-park violations directly cause traffic congestions and interrupt the normal flow of cars on the roads. In other words, drivers who do not stop correctly on the designated places contribute to the lingering travel times of road users. [5]. This issue results in a lot of problems, especially in POIs including commercial, administrative, and educational units. It should be noted that parking and departing from the park will slow down traffic and increase traffic accidents [6]. In many urban roads, there are parallel stops and even angled stops along the streets. Comparison of parallel parks with angled parks shows that car accidents in angled are 2 to 3 times larger than parallel [7, 8].

In a field study in a small area of Los Angeles by Shoup [9], the average distance travelled to find an appropriate park space by cars on the streets was estimated to be 3,600 miles per day. Drivers significantly reduce their speed, and increase their heart rate, when searching for street parking [10].In an analytical and quantitative study, Guo, Gao [2] using street-width variables and the number of moves required to perform a park, showed that stops along the streets had a significant effect on slower traffic and increased city trip time of other drivers. Chen, Conway [11] reviewed the New York City Data sets and found that the increasing demand for delivery of small packages has increased the parks along the streets. In other words, in a megacity of New York, traffic and the stops for delivery of goods have become a challenge.

The researches show that there is an association between on-street parking and crash risk [12]. A study in Montreal, Canada, showed that more than two-thirds of accidents with pedestrians occurred near the intersection of the streets. Therefore, it was suggested that some restrictions on the car park, speed limits in the streets and some simple prohibitions such as parking forbiddances near the intersections should be applied [13]. Humphreys, Box [14] showed that 49% of accidents happened on the main streets, 68% of accidents occurred in the streets to the highways, and 72% of accidents happened in the suburbs with stopped cars at the sides of the streets. Also, the findings of this study show that 20% of the total number of accidents is due to street side parks. The curb-parks near intersections seem to be one of the important cause of accidents due to disrupting the visibility of drivers when entering the intersections [15, 16].

Today, most of the large cities have become an industrial and automotive environment rather than a healthy place for humans. Promoting automobile driven and industrial approach to the city has created impassable roads for many citizens, including the elderly and the disabled people, heavy traffics, long highways and meaningless and depressing freeways. There is a global consensus on using the bicycle, public transportation and walking in order to achieve sustainable urban transportation, which reduces the use of private cars [17]. Gössling, Schröder [17] outlined that in the three studied cities, 58-59 per cent of the spaces allocated for urban transportation (parking and road space) is used by private cars. The study showed that only 1.3 to 4.1 per cent of urban transport space was allocated to cycling routes, while the space devoted to the car park is larger than the total bike path space. In another study in China showed that curb-parks reduced the number of e-bikes usage from 65% to 47% [18]. Also, the curb-parks increase the lane-crossing behaviour of non-motorized vehicles [19, 20]. It can be said that curb-park is one of the major obstacles to reaching a human-centred city and sustainable urban transportation.

GIScience can offer effective solutions for collecting, storing, retrieving, processing, analysing and displaying spatial data. Due to the its unique capabilities in solving spatial problems, and providing scientific and precise solutions in planning and decision making, their popularity has been increasing day by day, and their areas of application have become wider. In recent years, various studies have been carried out on the use of GIS tools in accident analysis and driving rules violations [21-24] attempting to boost urban safety and healthy urban living by shed lighting urban planning policies. In particular, Martens and Benenson [25] combined agent-based modelling with GIS tools to simulate driving behaviours in the car park. They demonstrated that usually, drivers are looking for a suitable park within 250-meter range of their target destination. Even drivers who use navigation services to find the shortest route search for a suitable park location after reaching the desired location [26]. Drivers who arrive without planning to reach their destination are trying to park in any possible way within the desired range. Therefore, the lack of planning for parking place has a major impact

99   on how to park based on the nature of the requirement of the stops (daily, administrative, emergency,
100   recreational, shopping, etc.). As surveys show, drivers who are not well aware of the location and
101   duration of the park are less sensitive to the correct way of the car park. Ajeng and Gim [27]
102   conducted a study in Indonesia and investigated an association between parking duration and
103   commercial type of land uses and streets characteristics.
104   World Health Organization (WHO) reported that 1.35 million people die every year on the roads
105   worldwide due to car accidents [28]. Table 1 shows the death per vehicle in Iran and some countries
106   in the year 2018.

Table 1. comparison of the vehicle per 1,000 population with death by car accidents per 100,000 vehicles in Iran and some countries (source: WHO 2018).

Country	Vehicle per 1,000 population	Death by accident per 100,000 vehicles
Iran	378	52
USA	873	12
Germany	691	6
UAE	366	21
Turkey	265	35

107   As shown in Table 1, the number of deaths per vehicle in Iran is more than eight an nine times
108   higher than in developed countries such as the USA and Germany respectively, and more than two
109   times to neighboring such as UAE. According to the Iranian Legal Medicine Organization (ILMO),
110   26% of those deaths were on city roads. The high volume of deaths per vehicle in Iran indicates the
111   need to study the violations and reasons for this issue.
112   Despite extensive studies in the modelling and analysis of accidents and urban violations, the
113   literature lacks of spatial analysis of vehicle park offences and their association with land use.
114   Therefore, the present study examines the spatial distribution of vehicle park offences along the
115   streets in an urban district of Tehran. Typically, these violations follow certain patterns, that
116   understanding these patterns can be used to make more efficient decisions to tackle the problem of
117   curb-park in cities.
118   The remainder of this paper is structured as follows. Section 2 presents the data used and
119   methods applied in the study. Section 3 presents our results, while discussing them in Section 4 and
120   presenting our conclusions in Section 5.

121   **1. Study area and Data**

122   *1.1. Study area*

123   The chosen study area is the 6th district of Tehran located in the centre of Tehran due to its
124   centrality and high occurrence of traffic violations. The chosen study area lies within with an area of
125   2137.9 hectares that located approximately in the centre of the city. It has 251,384 population based
126   on the census of 2016. The district's area is 3.3 percent, and its population is 2.9 percent of the city. It
127   currently holds more than 30 percent of governmental buildings, public and private institutions,
128   banks, and state organizations. In other words, the government management, decision-making
129   system as well as the city's modern business-economic system are located in the 6th district. The
130   combination of the above factors makes the area to demand regional and urban studies.
131   The study area contains big and crowded streets such as Azadi street, Enghelab Street, North
132   (Amir Abad) and south Karegar streets as well as Enghelab Square where they meet. The existence
133   of various kinds of POIs in the study area provided a unique situation to investigate their impact on
134   the curb-park violations. In addition, the accessibility to the study area facilitated the data collection

135   process. Figure 1 shows the study area and the selected regions on both sides of Enghelab Square
136   (region A (upper right) and region B (lower left)).

Figure 1. Study area.

137   Table 2 shows the characteristics of regions in the study area. The area of region B is 10% bigger
138   than region A, however, the length of streets that their curb-parks collected in region B is 20% longer
139   than region A ones.

Table 2. characteristics of regions in study area.

Parameter	Region A	Region B
Area *(ha)*	79.1	86.4
Population	6435	24570
Length of streets *(collected, km)*	8.65	10.50

140   *1.1. Data*

141   As per data collection, we used a free Android application called SW Map, which uses the built-
142   in GPS of the mobile phone with a five-meter accuracy. The accuracy of the system was good enough
143   to carry out this project. However, manual inspection was also applied to avoid large inaccuracies.
144   Since the focus of the study was on vehicle park violations, in the first step, a list of possible
145   infractions was collected through a field visit. The infractions after visiting the area is illustrated and
146   listed in Figure 2a and 2b. Any possible violation that may not include in the list was considered as a
147   legal park. The list was entered in the application, and the necessary settings for data collection were
148   done. The flowchart of our study is shown in Figure 3. Due to the fact that the curb-parks in the area
149   are temporary and dynamic, therefore a route was designed to collect data simultaneously on the
150   two sides of the streets. The data were collected from 10 AM to 13 PM, within four days. During this
151   time range, the usual traffic of Google shows the least congestion. Therefore, the effects of the rush
152   hour would be minimum. Data collection was done at the same time to avoid any additional errors
153   occurrence.

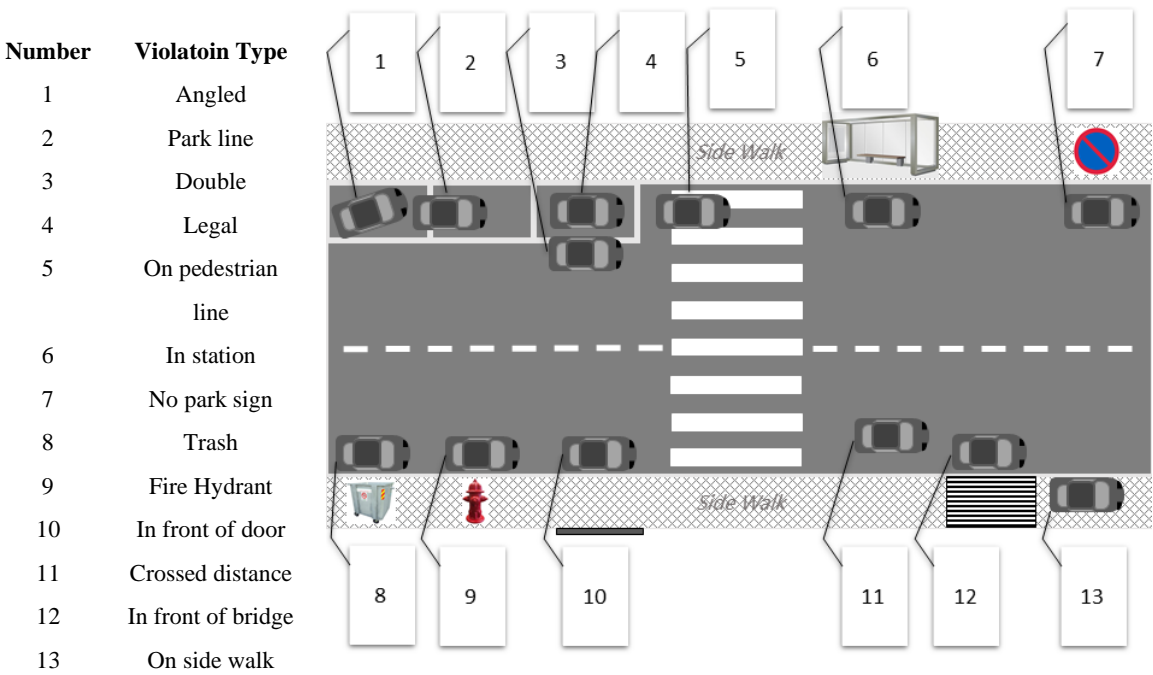| Number	Violatoin Type
1	Angled
2	Park line
3	Double
4	Legal
5	On pedestrian line
6	In station
7	No park sign
8	Trash
9	Fire Hydrant
10	In front of door
11	Crossed distance
12	In front of bridge
13	On side walk

Figure 2a. visual illustration of park violation types.

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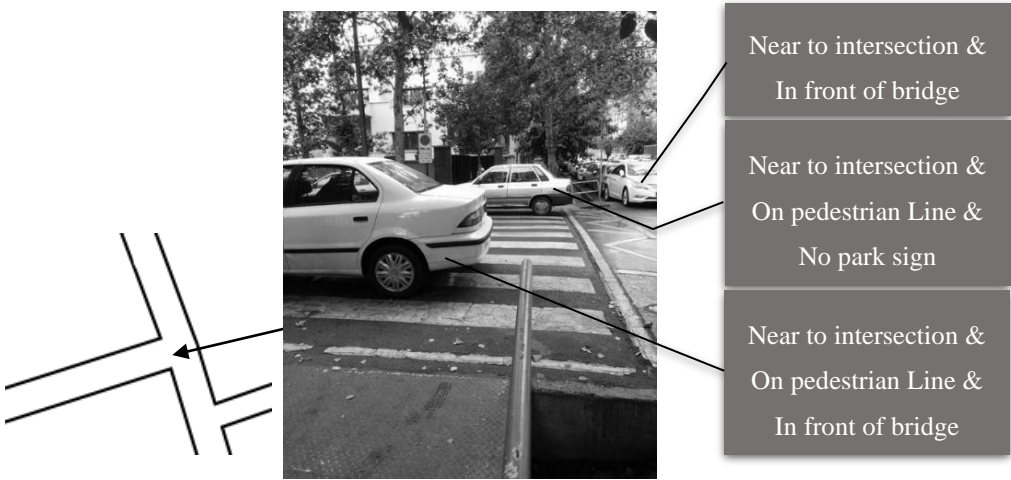
Figure 2. An example of park violations at the streets' intersection.
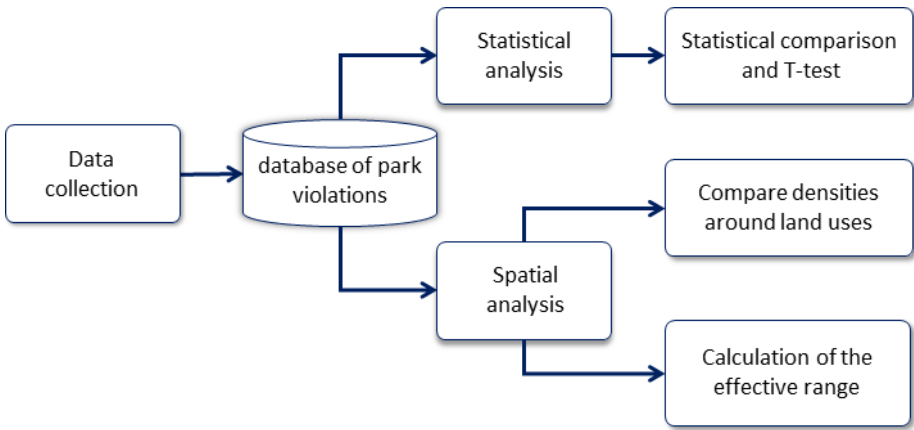
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Figure 3. Flowchart of the study.

1. Methods and results

1.1. Statistical analysis of traffic violations

The collected data were analysed statistically and spatially. Statistical analyses were performed based on the number of types of violations and comparison of the two regions within the study area. Table 3 shows the statistics of violations data in two regions, namely A and B. Since there was not any curb-park line in region B, there was not recorded any curb-park line violation except for 5 cases. The smallest violation number in both regions is the angled car park. However, the largest curb-park violation is park line, on bridge stop and double-parking in region A, respectively, while in region B the highest number is for double-parking and stopping on the sidewalk followed by stop on the pedestrian line.

Table 3. park violations' statistics in region A and B.

Violation Type	Region A	Region B
Angled	5	8
In Station	15	8
Crossed distance	20	18
In front of door	12	34
Close to intersection	47	37
Trash or Fire hydrant	30	40
No park sign	29	56
On bridge	94	67
On Pedestrian line	36	93
On Side walk	9	144
Park Line	134	5
Double	53	144
Legal	1222	1524
Total	1706	2181

167   The area of regions and their streets' length vary; therefore, we normalized the number of parks
168   based on the total number of illegal parks. Figure 4 graphically illustrates the comparisons of the
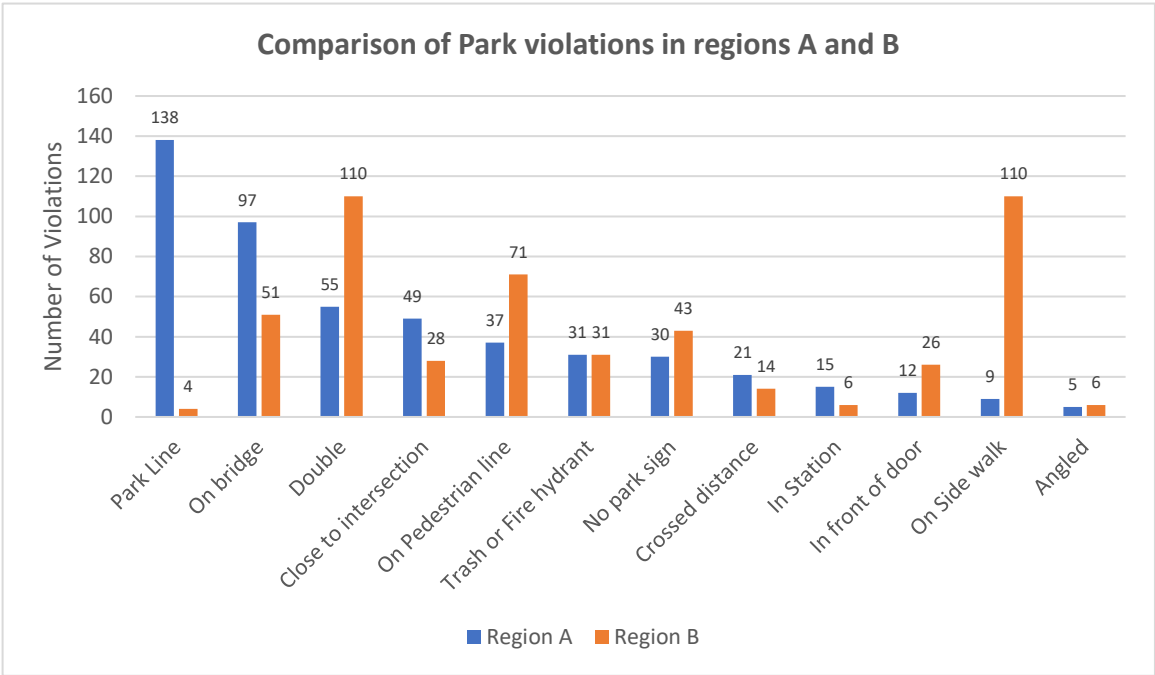169   curb-park violations.

Figure 4. Comparison of Park violations in regions A and B.

170   The bar chart of Figure 4 reveals some facts about the distribution of park violations in the
171   regions. Park line violation in region A is extremely higher than region B however, on sidewalk
172   violation in region B is highly bigger than region A. Also, double park and on pedestrian line
173   violation in region B is twice as big as region A ones. In contrast, on bridge park violation in region
174   A is two times bigger than region B. Although remaining park violations have different numbers,
175   they are negligible because of the small number of them. The investigations showed the reasons for
176   this discrepancy were in the spatial features of regions. Due to the lack of park line in region B, the
177   recorded park line violations are small. Also, the field visit showed that the width of sidewalks in the
178   region A was narrow. Therefore, stopping on the sidewalks was impossible.

1.1. Spatial analysis of traffic violations

180   Performing spatial analysis allowed us to analyse curb-park violations in terms of their patterns
181   and spatial distribution, which are depicted in the following sections.

1.1.1. Density of total stops

183   Figure 5 shows the maps of density of total stops, including both legal and illegal stopes. On
184   some streets such as Enghelab Street and Jomhoori Avenue, there is no congestion due to intense
185   surveillance of police on these streets, while in some areas there is a high density of stops. In region
186   A, there are two dense parts, which is because of a street march in that area during the data collection.
187   At the intersections, it seems that the stopping density is greater due to the impact of the points
188   on the crossroads. In other words, intersections have more than two traffic streams that make the
189   intersections as hotspots of curb-parks [29]. Also, this could be due to the nature of taking a taxi
190   along the streets in Iran as people raise their hand to take a taxi or taxi drivers stop along the streets
191   to pick up immediate passengers and often fill their cars with 4 passengers.
192   The question that arises is whether the park violations in the intersections are more than the
193   other parts of the streets? To answer this question, a buffer within a radius of 50 meters were drawn

194 to the centre of the intersections and the points were separated. Then, the statistics of inside and
195 outside of intersections were analysed separately, which is shown in Table 3.

Figure 5. Density analysis of total stops in region A and B.

196 The rate of stops, inside and outside of intersections relative to each other and to total stops is
197 approximately the same as for region A. While in region B, the number of illegal stops inside the
198 intersections is greater than the outside.
199 Figure 6 shows that region A with points inside and outside the intersections. As can be seen,
200 almost in all intersections there are curb-parks, except for the intersections with narrow streets which
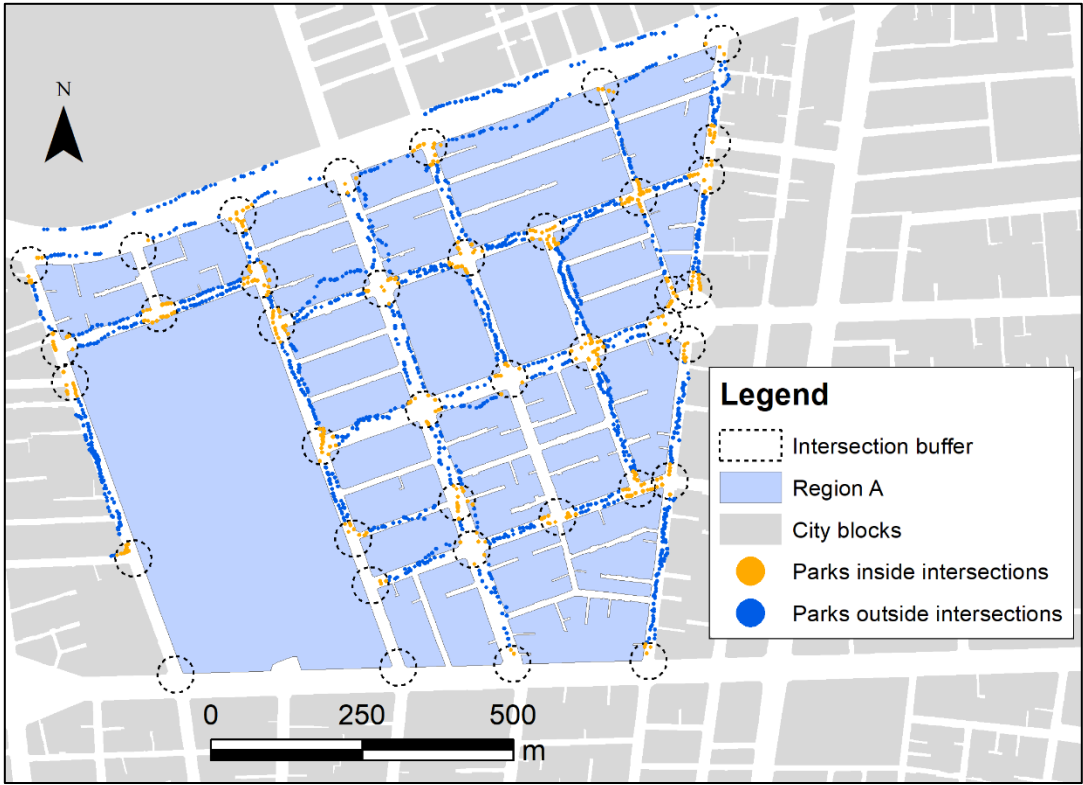201 is not possible due to the width of the road that makes the curb-park impossible.
202

Figure 6. points of inside and outside of intersections in the regions A.

203 In order to extract the spatial patterns of car park violations, the stops were divided into two
204 categories, legal and illegal. Figure 7 shows region A, B and the density of the stops. If the distribution
205 of legal and illegal stops is homogeneous, it is expected that the distribution of total, legal and illegal
206 stops have the same patterns. In other words, where the total stops' density is large, both legal and
207 illegal stops must have high density and vice versa. A close look at Figure 7 shows that this hypothesis
208 is not true in the entire study area. For example, around the University of Tehran, which is located in
209 the region A as a large block in the west of the map, there is a high density of stops in its northern
210 parts. However, the legal stops have a very high density around the campus, and the illegal stops are
211 sparse. Also, in the west part of region A, there is a high density of total and illegal stops while the
212 legal ones have relatively low density. However, according to Table 4 the number of legal stops is
213 always higher than illegal stops. Table 4 shows that approximately 70 percent of total stopes are legal
214 and 30 percent of all parks are illegal.

Table 4. Statistical comparison of stops inside and outside intersections in two regions.

Region A	inside	outside		Region B	inside	outside
Legal	293	923		Legal	283	1241
Illegal	115	369		Illegal	154	502
Total stops	408	1292		Total stops	437	1743
Legal/illegal	2.55	2.5		Legal/illegal	1.84	2.47
Legal/Total	0.72	0.72		Legal/Total	0.65	0.71
Illegal/Total	0.28	0.29		Illegal/Total	0.35	0.29

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216

217   *1.1. Influential factors in legal and illegal park densities*

218   With the argument presented in the previous section, it seems that some POIs affect how cars
219   stop. In other words, an amenity (such as a hospital) increases while other amenities (such as
220   university) decreases illegal stops. Features that have similarly high values were estimated using
221   Kernel Density Estimation (KDE)-. The KDE method is widely used in the finding clusters and
222   hotspots e.g., [30]. We considered the bandwidth of the kernel function 100 meters consistent with
223   impact range of POIs. To find the factors that affect the type of parks (legal or illegal), the density
224   map was overlaid on top of OpenStreetMap layer. The centres of the densest part were extracted. The
225   results show that the hospital is one of the most important factors in the creation of congestion in the
226   park violation. For example, as shown in Figure 8b, the location of Mostafa Khomeini hospital
227   overlapped with one of the illegal curb-park densities. Also, the entrance of Tehran University
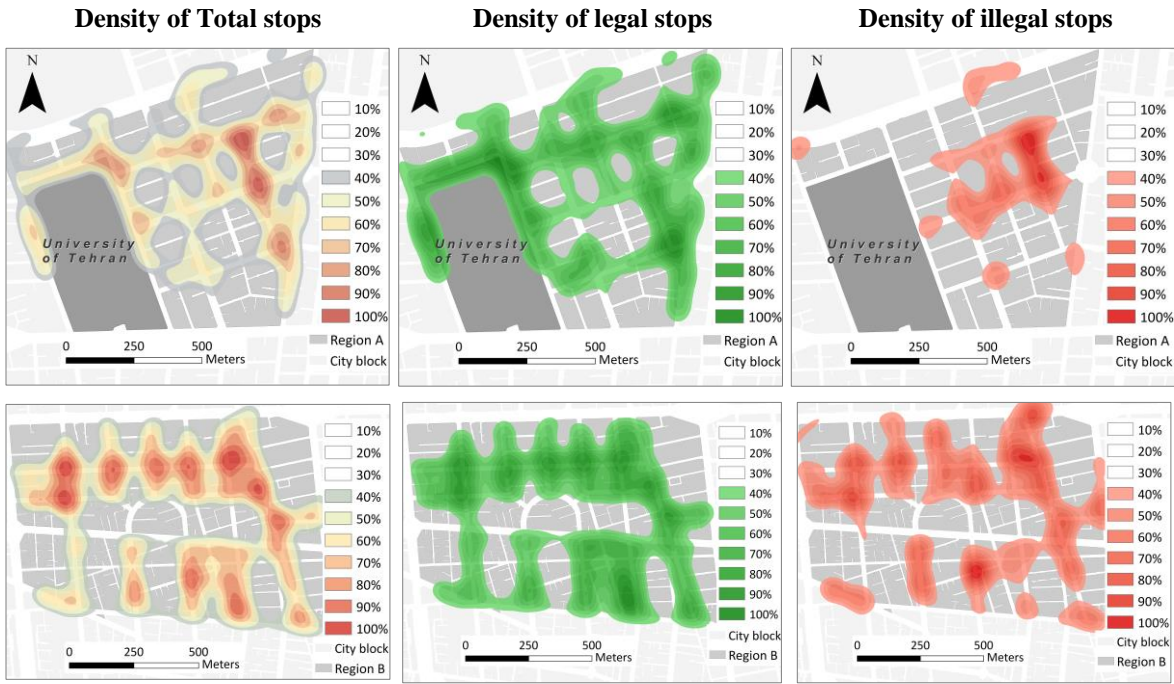228   matched on the legal stops' dense points.

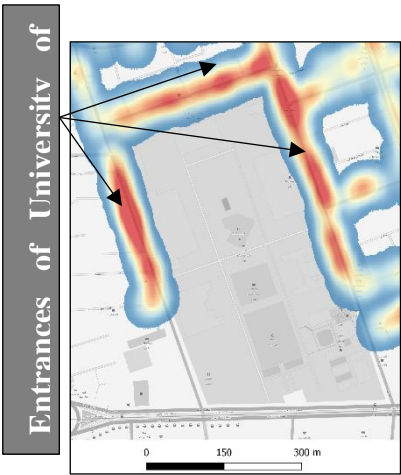**Figure 7.** Comparison of legal and illegal stops in regions A and B.

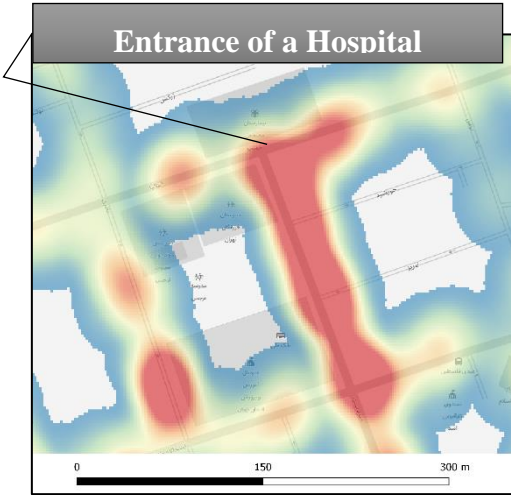**Figure 8.** POI and the legal stops density.   **Figure 8.** POI and illegal stops density.

229   A positive and direct relationship between the hospitals and the density of curb-parks violation
230   was clearly visible in the field visit. There were high densities of violated parks around hospitals.
231   Other influential POIs that were discovered after the mentioned method (overlaying maps) are
232   cinema, coffee shop, bank and bakery.
233   Visualising POIs on top of density maps shows that some POIs conform with the dense areas of
234   violated stops and legal stops match on another type of POIs.   Dense centres of legal stops that fit
235   the POI include colleges, libraries, and judicial centres. Also, Legal dense centres are far from illegal
236   dense centres. As can be seen in figure 7, around the University of Tehran, the legal stops are very
237   dense, indicating that curb-park rules are carefully heeded in this area. In the northwest corner of the
238   University of Tehran, there is also a judicial centre surrounded by proper stops.
239   With regard to the density of the legal and illegal stops around some of the POIs a hypothesis is
240   formed. This hypothesis states that stops, that seems to be planned or long are of the legal density.
241   For example, stops around the hospital cannot be planned and emerge as an emergency. Therefore,
242   the legal stops are less. While the stops around the library, the drivers have a prior plan and would
243   spend a long time there, so the legal stops are dense. In other words, the assumption of having a plan
244   ahead or not, and the duration of the stoppage justifies the stops density (whether legal or illegal).

1.1.1. Park violations around hospitals

246   To investigate park violations around hospitals the stops inside and outside 100-meter buffers
247   of hospitals were compared. Figure 9 shows the number of infractions found in and out of 100-meter
248   distance from hospitals. As the chart shows, the number of park-line violations and double-parks
249   have risen sharply around hospitals. The double park tripled and passing over park-lines nearly
250   doubled in the vicinity of the hospitals.
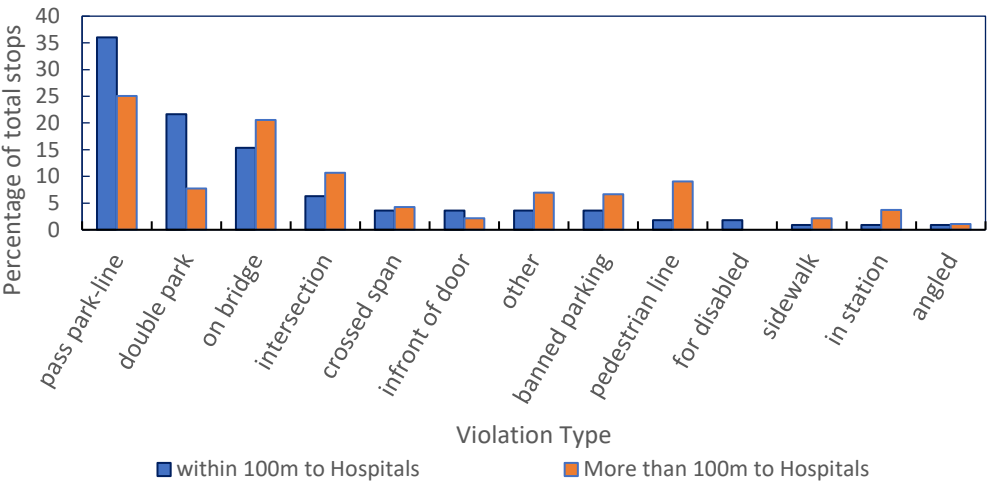

Figure 9. Comparison of the stop violations inside and outside of the 100-meter span of hospitals.

251   There is a statistically significant difference between the number of curb-park violations between
252   the zones, with a confidence level of more than 99.9%. According to the bar chart, the double park
253   and the park-line violations, within 100-meter distance from the hospital, are much higher than the
254   outside of the 100-meter range. Accordingly, the impact range of the hospital on increasing the
255   number of curb-park violations can be calculated.
256   The calculations show that there is not a significant difference between park violations within
257   100 meters and outside 100 meters to banks, supermarkets and schools. In other words, the patterns
258   of park violations around the mentioned POIs are as same as the average pattern of the study area.
259   Figure 10 shows the impact range of a hospital in occurring a park violation. The more distance
260   from the hospitals, the less illegal curb-parks and vice versa. The increase in the number of infractions
261   (at distances of more than 150 m) is due to the interference of the influence of other hospitals and
262   other factors. According to the diagram, the hospital has an impact zone of approximately 125 meters,

263 which is measured from the hospital entrance door. The impact range was calculated from the fitted
264 line. The reason for the last reduction (at a distance of more than 250 meters) is the limits of the study
265 area. As the distance from hospital increases, due to the lack of a recorded point outside the area, the
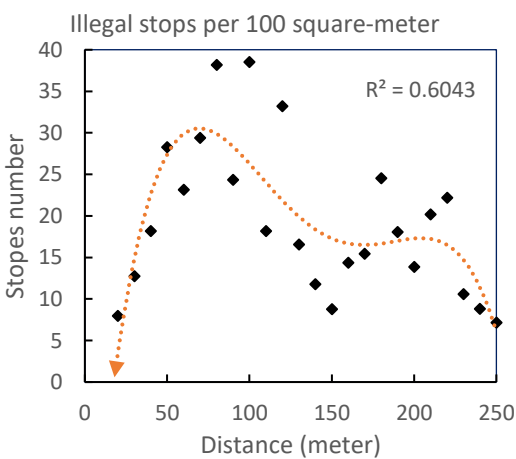266 number of violations decreased.
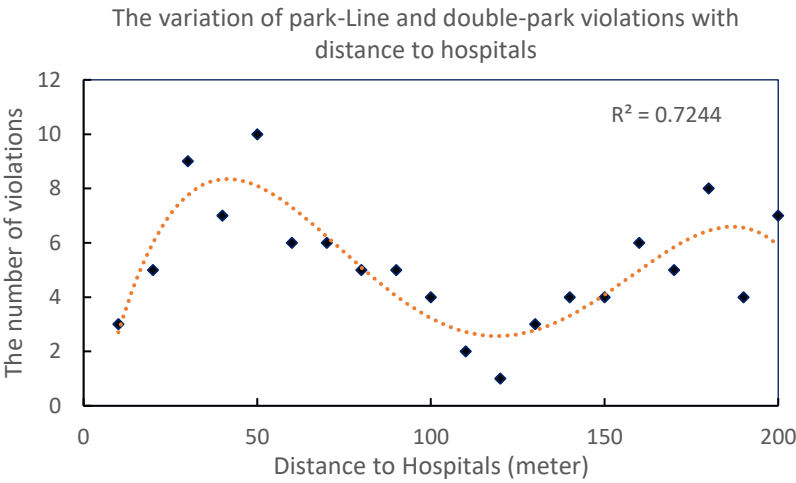
Figure 10. Diagram of the number of park violations with distance from hospitals.

267 1.1.1. park violations around POIs

268 Figures 11 and 12 show legal and non-accurate stops around the library, university, and judicial
269 offices. Closer to these POIs, the higher the legal stops. Conversely, closer to these POIs, the lower
270 the illegal stops. As can be seen, the impact range of these POIs calculable as same as the hospital.
271 The impact range of these POIs is nearly 100 meters.
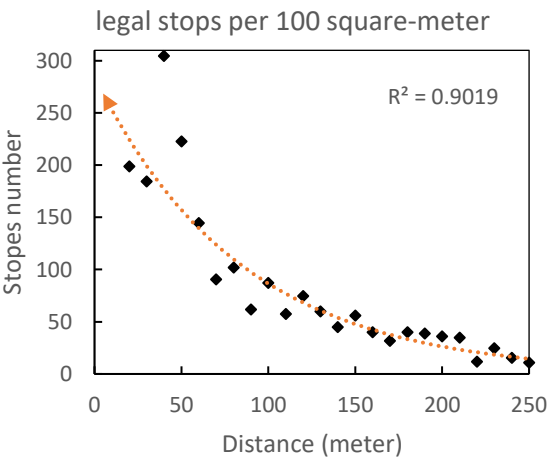
Figure 11. Increase of legal stops near the POI   **Figure 12.** Reduction of violations near the POI

272 **1. Discussions**

273 In this study, the relationship between vehicles stops in two regions of Tehran was investigated.
274 The results of the study showed that spatial analysis of parking violations can help discovering their
275 patterns as well as identifying influential factors of curb-park violations. The conducted analysis is
276 useful and can light shed urban planner and police department, law enforcement agencies among
277 others to have a better perspective of infrastructure planning. For example, the number of car park

278 violations around universities and libraries significantly decreased, while places such as hospitals,
279 cinemas, and bakeries absorbed the park's infractions. Prior plan and stop time seem to be two main
280 factors in how vehicles stop along streets [26]. This means that if the nature of the POI is such that
281 the clients need to plan ahead and a long standstill, the number of violations will decrease in that
282 spot. Conversely, influential POIs that require no prior planning to stop or the duration of the stop is
283 short result in a high number of violations.
284   The results of the survey showed that there are some differences in the features of two selected
285 study areas which reflected as the differences in the curb-park patterns. For example, the number of
286 parks on the sidewalk in the southern region of Enghelab Street is much larger than the northern part.
287 This problem can be due to the width of the sidewalks that are slightly wider than the northern part.
288 Therefore, parking on sidewalks is low in the northern part. In other words, there is no possibility of
289 parking on the sidewalk in the northern area. Also, park-line pass violation in the southern boundary
290 was much less than the northern boundary due to the lack of park-line in the southern region.
291   Although all streets of the northern part of the study area had park-lines, a small proportion of
292 violations was in park-line violation. Thus, it can be said that citizens have special attention to the
293 existence of car park lines. Contrary to the negative perception about drivers' breaking rules, the high
294 proportion of curb-parks between lines impressed authors during the data collection. Therefore,
295 urban decision-makers should pay special attention to the need for updating and maintenance of
296 park-lines.
297   As mentioned before, the co-existence of some amenities (POIs) on the dense points of illegal
298 stops show that there is a direct relationship between POI and curb-park violations. Using the
299 number of violations counted at the intervals of POIs, the range of POI influence was calculated. In
300 other words, there is a certain distance from a POI that within this range, combination and the
301 number of park violations differ with the average of the study area. For example, the impact range of
302 a hospital was estimated as 125 meters, which is also consistent with field observations.

1. Conclusions

304   Traffic violations within urban environments especially in large cities such as Tehran can have
305 negative impacts including increasing the volume of traffic, endangering the safety of citizens and
306 cars, and increasing air and voice pollutions and reducing quality of life. This problem is even more
307 extreme in developing countries where tradition and modernity in terms of using and adapting
308 infrastructure can cause conflicts for each other. For instance, the traditional taxi taking attitude in
309 the relatively modernized Iranian traffic infrastructure does not conform with the current driving
310 behaviours suitable for modern societies.
311   In this study, the spatial distribution of vehicle stops was investigated. Also, the number of curb-
312 park violations was estimated by using some parameters such as type and number of commercial
313 POIs. The POIs and the distance from them are the influential parameters on the number of legal and
314 illegal stops. The findings of this study showed that the distribution of curb-park violations around
315 some of POIs is different from the general pattern of the region. In other words, the number of stop
316 violations increases around some places and decreases around some others. For example, the number
317 of violations around hospitals increases and is different from the average of the area, as the double
318 park and park-line infractions dramatically increase around hospitals. While around other POIs such
319 as a university, the number of legal stops exceed the average of the region. The differences can be
320 seen up to a specific distance. Here, this distance is called the impact zone because, outside this zone,
321 both the number of violations and their combinations are different from inner part of the zone.
322 Therefore, the number of curb-park violations is predictable based on the type of POI. Therefore,
323 urban decision-makers can anticipate violations around each POIs according to the nature of each
324 one and take the necessary measures to reduce the number of violations or to install surveillance
325 cameras. Some POIs reduce park violations and seem no need to be monitored by local authorities in
326 those areas. While some POIs absorb car park infractions, therefore more monitoring can reduce the
327 number of violations.

328　　　　The study was conducted in two relatively different areas which differed in terms of traffic signs.
329　Despite the general thinking among people, the comparison of two regions of the study area, it was
330　found that drivers pay attention to the park lines and carefully stop within the lines. Therefore, it was
331　suggested that urban decision-makers should pay special attention to the updating of park-lines in
332　the city.
333　　　　According to field survey, car park violations cause instant traffic, and sometimes even lead to
334　accidents between cars or pedestrians. As per future directions, comparison of accidents' quantity
335　and curb-park infractions is recommended. Curb-Park violations can cause instant traffic jams.
336　However, it was not possible in this study to measure the instant traffic and car park infractions
337　simultaneously and hence could be another potential lead for future work.
338

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