# Analysis of Depedences between Using of Parking Places and Chosen Parameters of Weather on the Example of Underground Parking in Cracow

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**Abstract.** The development of civilization is connected with the development of cities. This is particularly visible in high developed countries. Dynamic increase of the population and enlarging its grounds causes many problems. One of the problem, which is the most difficult to solve, is the problem of parking in cities as well as the problem of increasing number of cars, particularly personal cars. This problem results from several main reasons: 1. The historical form of cities, 2. Tendencies to building in city centres the main administrative centres, departments, offices, schools, universities, shopping centres etc., 3. Tendencies to transfering residences from cities to villages situated near cities. This phenomenon occurs especially in the well-off part of the society. It generates the additional traffic of personal cars and the growth of the demand on parking places. 4. Increasing price accessibility of personal cars. Observations taken by the author of the paper show that vehicles traffic in a city grows up when the weather get worse. There was submitted a proposition that this will influence on the extent of utilization of car parks and zones of paid parking in a city. The aim of the investigation was checking the dependence between the chosen weather parameters, e.g. temperature, falls, cloudiness, and the utilization of parking places. Underground car park in Cracow was chosen as the object of investigations. Cracow is one of the largest cities in Poland. About 760000 persons live there, and in Cracow Agglomeration about 1.4 million of persons. There are great parking problems in the city. Because of that the zones of paid parking have been introduced, where can be parked about 29000 personal cars. The analysed car park is the new object. It is administered by the company, which belong to the town. It may be attractive for drivers because of its position, about 1 km from Old Town Market. However, there exist another car parks, which are laid even nearer, but they do not have the roof which can be important for drivers, when the weather is rainy or it snows. The article presents dependences between weather and utilization of the car park as well as mathematical calculations which describe phenomena being studied.

## 1. Introduction

Ground, air and water are natural supplies which state is worse and worse because of civilization development. One of the factors exerting a big influence on that is transportation, especially road transportation. The transportation influences natural environment by elements of infrastructure, e.g. roads, bridges, car parks, as well as cars that is fumes, noise, vibrations. On the other hand, the natural environment, and especially weather, exert on drivers. We can notice the growth of intensity of cars together with deterioration of weather. This is caused by drivers' comfort and expected smaller time of a trip by own car than by public transportation. The increase of number of trips influences on cities' crowd, including car parks. The article undertakes a trial of researching the effect of weather on parking places' occupation.

In literature one can find other, different models of car parks' functioning, [6]. M. Nourinejad, M. J. Roorda produced the model of setting parking prices [1]. L. Guo, S. Huang, J. Zhuang, A. W. Sadek in their paper write, among others, about the role of drivers' psychological proprieties in process of choice of parking places [2]. Those authors paid attention to defining environmental costs connected with seeking parking places [3]. Parkitny W. introduced logit models to predict the behaviour of personal vehicles' drivers with reference to car parks choice [4]. F. Zong, Y.-S. Zhang, Z.-Z. Wang, Z.-Y. Li show the manner of using the theory of games to describe relation between car parks' administrators and drivers [5]. Parkitny described how to use the theory of games to modelling equipment and prices of car parks. Modifying prices for parking as well as car parks' equipment, administrators of car parks can affect the enlargement of car parks' attractiveness and enlarge financial receipts from payments for parking [6]. Authors of the publication [7] paid attention to data's credibility of models of information systems about parkings. W. Young, R. G. Thompson, M. A. P. Taylor, performed a review of urban car parking models [8]. Another car parks models, including those that use the theory of games, may be found e.g. in papers [9, 10, 11, 12, 13, 14, 15, 16].

## 2. Description of objects, aim and method of the investigations

As the object of the investigations, car park in Aleja Mickiewicza 18 in Cracow was chosen. Cracow belongs to the largest cities in Poland. Cracow has about 760000 of occupants, and Cracovian agglomeration is about 1400000 persons. The large number of vehicles belonging to occupants and tourists causes the congestion of movement and big problems with finding vacant parking places. On account of that there have been introduced the limitation of movement and paid parking zones in the city centre and districts located nearby [17, 18]. The zone of paid parking in Cracow, administered by the company belonging to the city, has possessed 28837 parking places in 28.01.2016.

The studied car park is a non-watched one. It is open 24 h, 7 days in week. It has 150 parking places, 4 places for handicapped and 1 place for families with children. On the premises of the car park there are 4 entries/exits, monitoring, employees of service, toilets, lift for handicapped persons, regulations of using the car park, cash device. Payments may be done also by payment cards. Internal roads on the car park are marked with perpendicular road signs, too. The car park has good connections by public transportation with other parts of the city. There are halts of 18 daytime tram lines and bus lines as well as 3 night lines in the vicinity. The car park lays near the city center, however one can find different car parks located nearer. There is about 1 km to the Main Market, 1.5 km to the Wawel Royal Castle and Wawel Cathedral, about 1 km to Municipal Office, 1.5 km to ICE Cracow conference center. It is also near to the National Museum in Cracow, Cracovian Błonia, Jagiellonian University, Jagellonian Library, Akademia Górniczo - Hutnicza, Municipal Stadium, Cracovia Stadium, Cracovian Planty, Old Town.

The aim of the research was checking the influence of the weather on the size of demand for parking places. Observations of vehicles' movement intnsity in the city taken by the Author of the paper show, that during the days of bad weather, the intensity of vehicles' movement grows up. It may cause the growth of demand for parking places. However, the considerably more important problem is the growth of air pollution. The air pollution can result in some part from contamination by cars' exhaust fumes. That is a serious problem in Cracow becaus the city belongs to the cities which have the most polluted air in Europe. Examining of the vehicles' movement intensity on all roads in the city is very difficult. It is easier to measure the occupancy of parking places. To do this one should check the number of entrances and departures of vehicles on a car park, which is possible in case of car parks which have the electronic parking systems to publishing tickets or detectors of vehicles' position. Unfortunately, there are only several of such municipal car parks. One of them was chosen to the survey.

The data concerning the occupancy of parking places and kinds of parking subscriptions were got from the enterprise Miejska Infrastruktura sp. z o. o. in Cracow. This company administers the car park being analysed by the Author of the article.

The data refering to the weather come from Instytut Meteorologii i Gospodarki Wodnej - Polski Instytut Badawczy. The measurements of the weather had been executed by meteorological station Cracow Balice.

### 3.  Results and discussions

To check up the influence ofweather paremeters diversified in time on parking, there had beed chosen to analyses two characteristic months of the Ist half of the year 2017, that is January and April. January was chosen for winter conditions, and first of all for the low air temperatures. April is characterized by the largest rain falls.

Weather parameters being analysed are:

1. overcast sky,
2. air temperatura[$^{o}$C],
3. sum of rainfall [mm],
4. fog – time of duration in twenty-four hours [h],
5. time of rime duration [h],
2. visibility [m].

Cloudiness is marked according to the scale: 0/8 – cloudless, 1/8 – sunny, 2/8 – scattered clouds, 3/8 – lightly cloudly, 4/8 – partly cloudly, 5/8 – cloudly, 6/8 – mostly cloudly, 7/8 – nearly overcast, 8/8 – overcast, 9/8 – sky obscured.
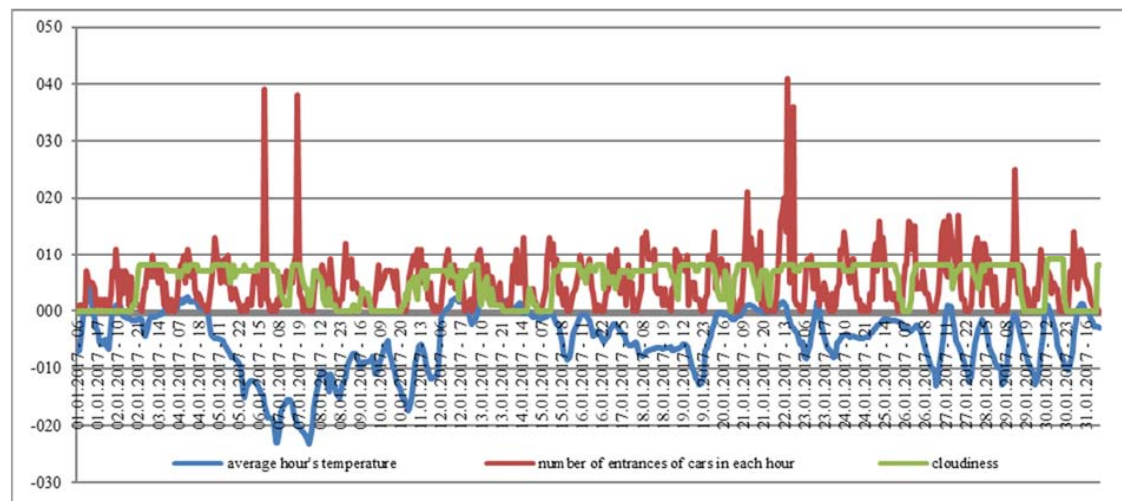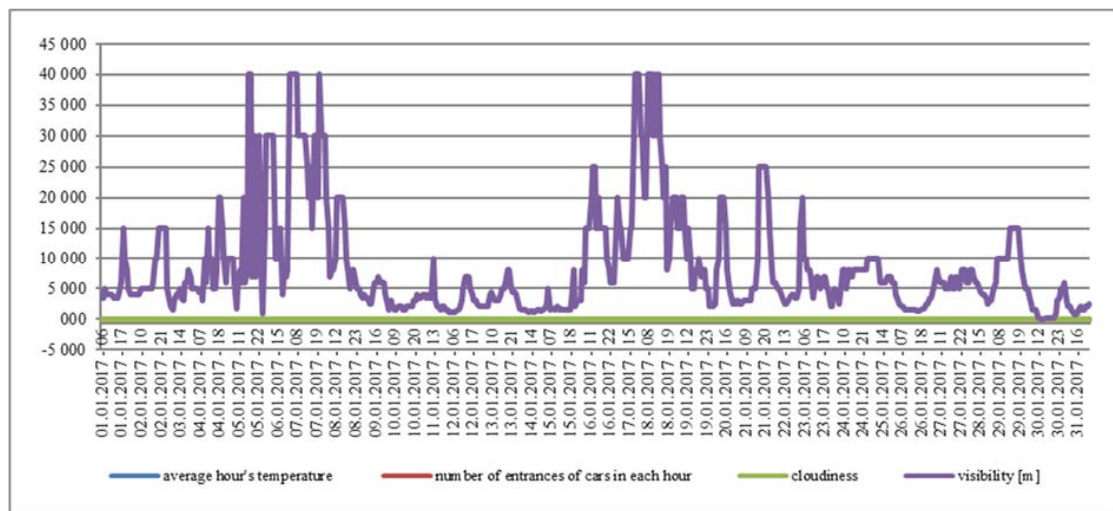


**Figure 1**. Dependence between average hour's temperature for all days in January, cloudiness and number of entrances of cars to the car park in each hour

The figure 1 shows the dependence between average hour's temperature for all days in January, cloudiness and number of entrances of cars to a car park in each hour.  The figure 2 displays visibility, cloudiness, average 24 hours' temperature for January as well as the number of entrances of cars on the studied car park.

The coefficients of correlation were chosen as the measure of influence of weather parameters on the number of entrances of cars on the car park.  It was assumed that if the coefficient of correlation $r_{xy}$ = 0 then there is the lack of correlation relationshipis between studied features. For $r_{xy} \leq 0.3$ correlation is minute, for $0.3 < r_{xy} \leq 0,5$ correlation is medium and for $r_{xy}>0,5$ correlation is clear [19].

The coefficients of correlation for January 2017 year figure out:

1. coefficient of correlation between average 24 hours' temperature and the number of entrances of cars to the car park during twenty-four hours amounts 0.07417,
2. coefficient of correlation between volume of falls in [mm] during twenty-four hours and the number of entrances of cars to the car park during twenty-four hours' amounts (- 0.0535),
3. coefficient of correlation between time of duration of fog during twenty-four hours and the number of entrances of cars to the car park during twenty-four hours' amounts (- 0.14158),
4. coefficient of correlation between time of duration of rime during twenty-four hours and the number of entrances of cars to the car park during twenty-four hours' amounts (- 0.14158).

**Figure 2.** Dependence between visibility, cloudiness, average 24 hours' temperature for January as well as the number of entrances of cars on the studied car park

There were also counted coefficients of correlation between parameters of weather easy to notice by drivers, i. e. cloudiness and temperature and the number of entrances of cars to the car park. Those calculations were made for morning tops of intensity of vehicles' movement, that is in hours 6.00-9.59 for days from Monday to Friday as well as in hours 6.00 - 23.59 (considering different way using the car park) for Saturdays and Sundays (table 1).

**Table 1.** Coefficients of correlation temperature/ entrances of cars to the car park as well as cloudiness/ entrances of cars to the car park

| Days | Coefficient of correlation temperature/ entrances of cars to the car park in hours 6.00 - 9.59 | Coefficient of correlation cloudiness/ entrances of cars to the car park in hours 6.00 - 9.59 |
|---|---|---|
| Mondays | 0.16716 | -0.1123 |
| Tuesdays | 0.43457 | 0.1068 |
| Wednesdays | -0.02105 | 0.1512 |
| Thursdays | -0.13047 | -0.27837 |
| Fridays | 0.62858 | -0.23606 |
| | **Coefficient of correlation temperature/ entrances of cars to the car park in hours 6.00 - 23.59** | **Coefficient of correlation cloudiness/ entrances of cars to the car park in hours 6.00 - 23.59** |
| Saturdays | 0.04295 | 0.16888 |
| Sundays | 0.34456 | 0.29957 |

Coefficients of correlation for April 2017 figures out:
1. coefficient of correlation between average 24 hours' temperature and the number of entrances of cars to the car park during twenty-four hours amounts 0.18933,
2. coefficient of correlation between volume of falls in [mm] during twenty-four hours and the number of entrances of cars to the car park during twenty-four hours' amounts (- 0.09741),
3. coefficient of correlation between time of duration of fog and rime during twenty-four hours and the number of entrances of cars to the car park was not counted, because there had been no fog and rime in April.

Figures 3 i 4 presents the graphs of dependence of numbers of vehicles entering to the car park in each day and weather parameters.
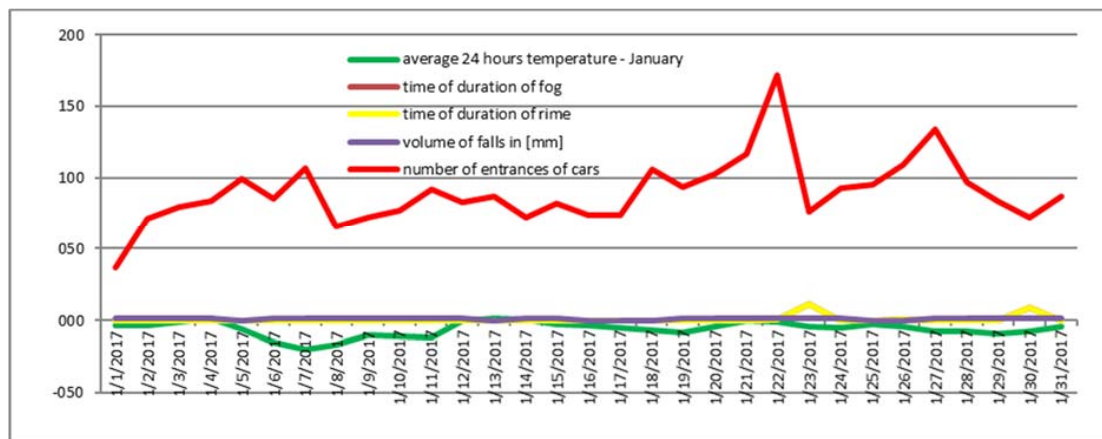
**Figure 3.** The graphs of dependence of numbers of vehicles entering to the car park in each day and weather parameters for January 2017
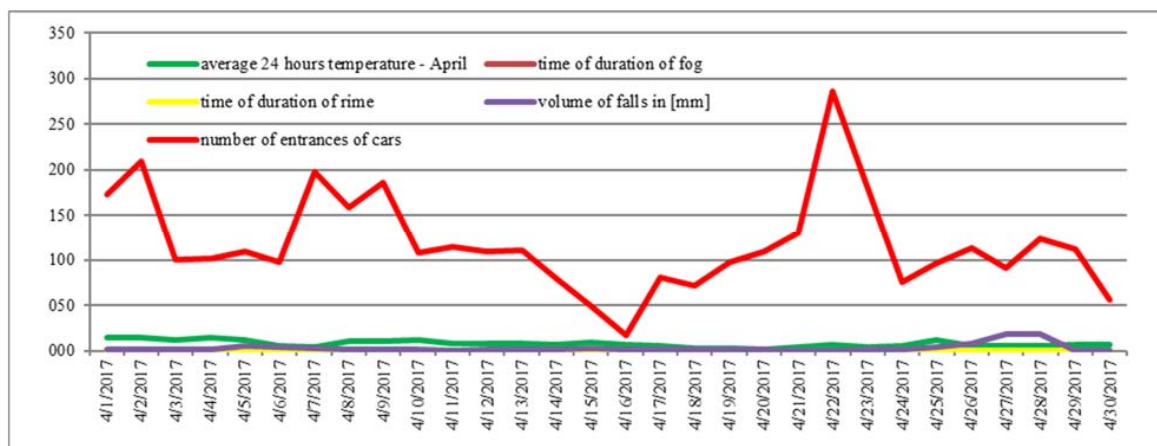


**Figure 4.** The graphs of dependence of numbers of vehicles entering to the car park in each day and weather parameters for April 2017

The investigations proved, that for examined 2 months those correlational dependences were mostly weak. This may mean that the growth of number of vehicles that could be observed onstreets in rainy days, has no relation with the number of cars parking on this analysed car park. The received results induced the Author to search the reasons of that phenomenon.

It was assumed that the decision about using a private car is connected first of all with cars' entrances to the car park, and the time of parking and departures depend on the aim of a trip. Because of that the hours and the number of entrances of vehicles have been studied. Entrances have been analysed on the ground of bought single tickets and subscription cards. After preliminary analysis hourf from 0.00 to 5.59 were skipped, because entrances at those hours were sporadic. The coefficients of correlation of vehicles' entrances to the car park in analogous days of week were studied. It turns out that the obtained coefficients of correlation in majority of cases are high (table 2). This may mean that trips and related to that parking of cars are determined by other factors, e.g. commuting to the work place, and the weather is a factor being left out of account while taking decision about choice of a private car as a mean of transportation.

Coefficients of correlation different than high were got only for:
1. for January:
   a) medium correlations (0.44431) for Mondays 2/9.01.2017,
   b) medium (0.39215) for Tuesdays 17/31.01.2017,
   c) low for Fridays 6/13.01.2017: (-0.12197) as well as 6/20.01.2017: (0.16906),
      for Sundays medium: 1/8.01.2017: (0.48629) as well as 22/29.01.2017: (0.4519).

**Table 2.** Table of correlations

| Mondays | | Tuesdays | | Wednesday | | Thursdays | |
|---|---|---|---|---|---|---|---|
| 2/9.01.2017 | 0.44431 | 3/10.01.2017 | 0.83455 | 4/11.01.2017 | 0.76528 | 5/12.01.2017 | 0.779 |
| 2/16.01.2017 | 0.62589 | 3/17.01.2017 | 0.69576 | 4/18.01.2017 | 0.8227 | 5/19.01.2017 | 0.81252 |
| 2/23.01.2017 | 0.63957 | 3/24.01.2017 | 0.80251 | 4/25.01.2017 | 0.63988 | 5/26.01.2017 | 0.68985 |
| 2/30.01.2017 | 0.5789 | 3/31.01.2017 | 0.65593 | 11/18.01.2017 | 0.70089 | 12/19.01.2017 | 0.70723 |
| 9/16.01.2017 | 0.65957 | 10/17.01.2017 | 0.70491 | 11/25.01.2017 | 0.81334 | 12/26.01.2017 | 0.7514 |
| 9/23.01.2017 | 0.72543 | 10/24.01.2017 | 0.67107 | 18/25.01.2017 | 0.76939 | 19/26.01.2017 | 0.73973 |
| 9/30.01.2017 | 0.75888 | 10/31.01.2017 | 0.64216 | - | - | - | - |
| 16/23.01.2017 | 0.6279 | 17/24.01.2017 | 0.62938 | - | - | - | - |
| 16/30.01.2017 | 0.70731 | 17/31.01.2017 | 0.39215 | - | - | - | - |
| 23/30.01.2017 | 0.61168 | 24/31.01.2017 | 0.69888 | - | - | - | - |
| 3/10.04.2017 | 0.72909 | 4/11.04.2017 | 0.73633 | 5/12.04.2017 | 0.84108 | 6/13.04.2017 | 0.73286 |
| 3/17.04.2017 | 0.34038 | 4/18.04.2017 | 0.61598 | 5/19.04.2017 | 0.80169 | 6/20.04.2017 | 0.74001 |
| 3/24.04.2017 | 0.80485 | 4/25.04.2017 | 0.78288 | 5/26.04.2017 | 0.62029 | 6/27.04.2017 | 0.7673 |
| 10/17.04.2017 | 0.3842 | 11/18.04.2017 | 0.7797 | 12/19.04.2017 | 0.79564 | 13/20.04.2017 | 0.66852 |
| 10/24.04.2017 | 0.84719 | 11/25.04.2017 | 0.65634 | 12/26.04.2017 | 0.74703 | 13/27.04.2017 | 0.66916 |
| 17/24.04.2017 | 0.16152 | 18/25.04.2017 | 0.60929 | 19/26.04.2017 | 0.60857 | 20/27.04.2017 | 0.83493 |
| **Fridays** | | **Saturday** | | **Sundays** | | - | - |
| 6/13.012017 | -0.13197 | 7/14.01.2017 | 0.00734 | 1/8.01.2017 | 0.48629 | - | - |
| 6/20.01.2017 | 0.16906 | 7/21.01.2017 | 0.48425 | 1/15.01.2017 | 0.77492 | - | - |
| 6/27.01.2017 | 0.51459 | 7/28.01.2017 | 0.17473 | 1/22.01.2017 | 0.53011 | - | - |
| 13/20.01.2017 | 0.66658 | 14/21.01.2017 | 0.71807 | 1/29.01.2017 | 0.68686 | - | - |
| 13/27.01.2017 | 0.61341 | 14/28.01.2017 | 0.60221 | 8/15.01.2017 | 0.64715 | - | - |
| 20/27.01.2017 | 0.68604 | 21/28.01.2017 | 0.47554 | 8/22.01.2017 | 0.55852 | - | - |
| - | - | - | - | 8/29.01.2017 | 0.60156 | - | - |
| - | - | - | - | 15/22.01.2017 | 0.55038 | - | - |
| - | - | - | - | 15/29.01.2017 | 0.51166 | - | - |
| - | - | - | - | 22/29.01.2017 | 0.4519 | - | - |
| 7/14.04.2017 | 0.24983 | 1/8.04.2017 | 0.82152 | 2/9.04.2017 | 0.66199 | - | - |
| 7/21.04.2017 | 0.10102 | 1/15.04.2017 | 0.83306 | 2/16.04.2017 | 0.49085 | - | - |
| 7/28.04.2017 | 0.10541 | 1/22.04.2017 | 0.41691 | 2/23.04.2017 | 0.65703 | - | - |
| 14/21.04.2017 | 0.66588 | 1/29.04.2017 | 0.78966 | 2/30.04.2017 | 0.39386 | - | - |
| 14/28.04.2017 | 0.22999 | 8/15.04.2017 | 0.8053 | 9/16.04.2017 | 0.30855 | - | - |
| 21/28.04.2017 | 0.28504 | 8/22.04.2017 | 0.35011 | 9/23.04.2017 | 0.79853 | - | - |
| - | - | 8/29.04.2017 | 0.7425 | 9/30.04.2017 | 0.12403 | - | - |
| - | - | 15/22.04.2017 | 0.20208 | 16/23.04.2017 | 0.63521 | - | - |
| - | - | 15/29.04.2017 | 0.63672 | 16/30.04.2017 | 0.42338 | - | - |

2. for April:
   a) medium correlations for Mondays 3/17.04.2017: (0.34038) as well as 10/17.04.2017: (0.3842), low (0.16152) for 17/24.04.2017,
   b) Fridays - only high between days 14/21.04.2017, correlation between remaining Fridays are positive, but weak,

c)  Saturdays 1/22.04.2017 coefficient of correlation figured out 0,41691, and between days 8/22.04.2017 figured out 0.35011, so it was medium, yet between 15/22.04.2017 figured out 0.20208, so it was low,

d)  coefficients of correlation between Sundays: 2/16.04.2017: (9.49085), 2/30.04.2017: (0.39386), 9/16.04.2017 (0.30855) and 16/30.04.2017: (0.42338) were medium, and for 9/30.04.2017 (0.12403) the coefficient was low.

The greater differentiation of the coefficients of correlation in weekends results from a larger participation of facultative trips in days free of work. To such trips are ranked among others: shopping, visits, touristic voyages, mass events etc. It is especially noticeable in April, when the temperatures were higher, and different weather conditions more favourable than in January.
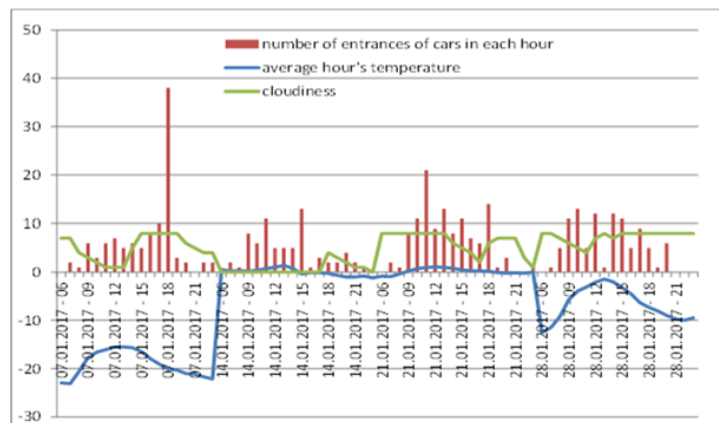
Analysing the reasons of smaller interest in the car park than it had been originally presumed, one may notice, apart from above mentioned causes, that the studied car park is relatively new and underground. Despite of marking and information boards it can be skipped by drivers. Its location can be also considered as a middling attractive in relation to the distance to the Main Market Square.
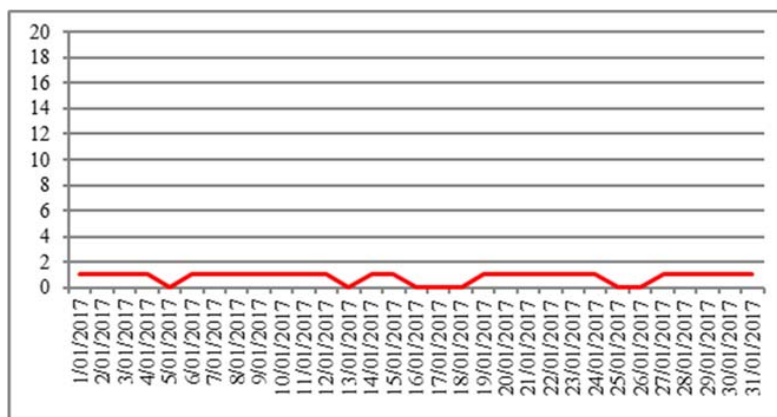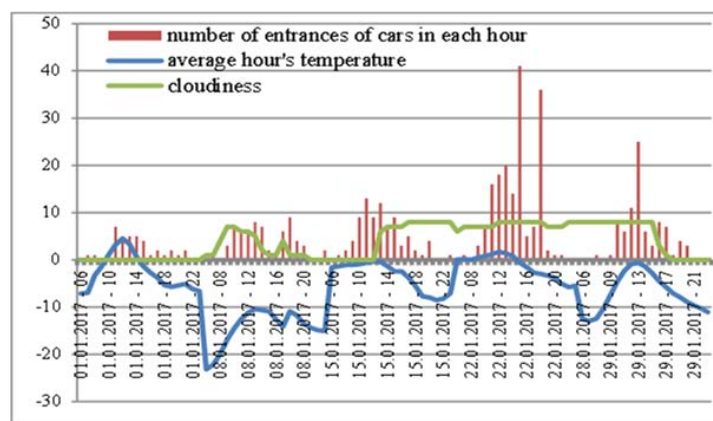


**Figure 5.** Volume of 24 hours' rain falls in [mm] in January 2017
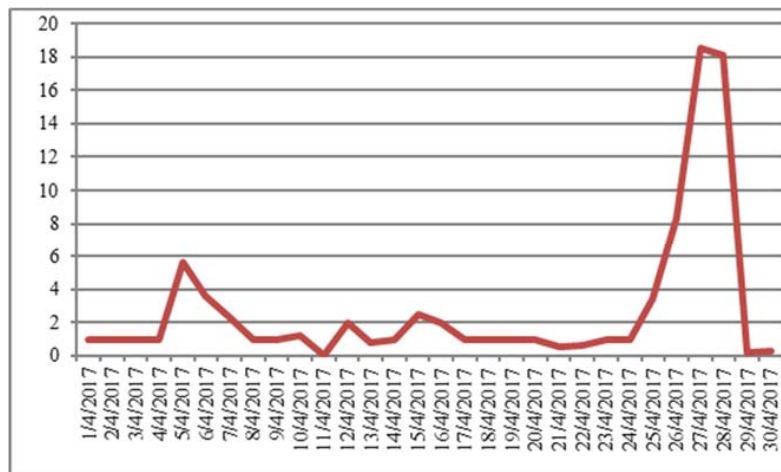


**Figure 6.** Volume of 24 hours' rain falls in [mm] in April 2017

**Figure 7.** Dependence between the number of entrances of cars to the car park and cloudiness as well as temperature in particular hours for Saturdays in January.



**Figure 8.** Dependence between the number of entrances of cars to the car park and cloudiness as well as temperature in particular hours for Sundays in January.

## 4. Conclusions

1. Analysing the reasons of smaller interest in the car park than it had been originally presumed, one may notice, that the studied car park is relatively new and underground so it can be skipped by drivers and its location can be also considering as a middling attractive in relation to the distance to the Main Market Square. Models of parking locations are described in the article [20].

2. The volume of rain falls in the month, which was the rainiest in the Ist half of year 2017, that is in April, did not belong to the high ones (figure 5 and 6). The fleeting rain falls of could be disregarded as an essential factor in choice of private car as an alternative mean of transportation.

3. The weather can change in time, sometimes dynamically, especially in the spring during storms. It may be diversified geographically too, that is different in the spot of making measurement in downtown, and different in place of beginning of a trip. The accomplished analysis of correlation of weather parameters and occupation of parking places didn't include time shifts, that is time which pass from taking decision about the choice of personal car as a mean of transportation when the weather conditions are unfavourable, till the moment of arrival of a car to the car park. That time can be very diversified. It depends among others on the distance of drive to the city centre and situation on streets in the city, including traffic-jams. To estimate it one should know places of beginning of the drivers' trip. Unfortunately, the existing base of data doesn't contain such information. In figure 7 and 8 the dynamics of weather changes in particular hours for chosen of days is presented.

4. A large group of the car park's users are persons who bought monthly parking subscriptions. Because of earlier, sometimes with several weeks' preceding, payment for parking service, Author of the article supposes, that decisions about choice of transportation mean of this drivers' group are in great part determined by previous decision about purchase of parking card. Because of that the influence of weather is marginal.

5. From the  operation research and multicriterion analysis's point of view point, the building of mathematical model which shows the dependence between the weather and the degree of car parks' utilization is a difficult question. Very difficult issue is, among others, precise forecasting of weather.

6. The investigator has the access only to the parameters, which was can be measured, e.g. the degree of car park's occupation, or weather parameters, e.g. temperature, pressure, volume of falls etc. On decision about utilization or non utilization of a car park also has influence a large number of other factors, including e.g. psychological ones. One can number to them: individual drivers' preferences which do not depend on weather, degree of importance of weather as a factor effecting on decision about choice of transportation mean, organization of movement in city, foreseen level of the vehicles' movement congestion, comfort of travel, driver's hurry, prestige connected with possession of a car of prestige brand, necessity of taking other members of family in a trip, e.g. children to school etc. About those factors the research worker does not know or has to execute additional, complicated and expensive investigations.

7. A part of drivers' decisions about choice of transport mean or parking place are unaware decisions.

8. The knowledge of drivers' behaviours connected with parking, in dependence on the state of weather can has practical application. Enlarging the price for parking in days of bad weather one can effect on the size of demand. The limitation of demand can next influence on limitation of air pollution deriving from cars' movement. Vehicles going to the centre must park somewhere. If the price for parking is too high, it will force a part of drivers to resign from trip in personal cars and to travel by more ecological public transportation. Such a solution is not possible in Poland at present because of legal restrictions. It grows up, however, the pressure of cities authorities to change the regulations in order to raise parking rates. So maybe in future there will be introduced prescriptions about elastic parking rates, related to e.g. demand on parking places. It would allow to limit the vehicles' movement in downtowns.

9. The investigated car park is comparatively small (150 lots) in relation to almost 29 thousands places in  the paid parking zone which is administered by a company belonging to the city and a dozen or so thousands of places on car parks and private estates. This is also atypical car park, because comparatively new and underground. Investigations realizad earlier by the Author show the bigger acceptance for ground car parks than underground ones, and so not all drivers will take it into consideration in plans of their journeys [21]. Owing to that the received results can differ from general results.

10. Large car parks, regardless of the weather, can generate large traffic [22].

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