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The Impact of Weather on Traffic Speed in Urban Area

Jacek Chmielewski [1], Marcin Budzynski [2]

[1] Al. Kaliskiego 26/24, 85-796 Bydgoszcz, Poland
[2] Gabriela Narutowicza 11/12, 80-233 Gdańsk, Poland

jacek-ch@utp.edu.pl

Abstract. The issue of the impact of weather conditions on trip speed of vehicles has been studied for a long time and it is still the subject of many scientific researches. The impact of atmospheric conditions on the speed with which drivers drive their vehicles seems to be obvious. Good weather conditions, sunny weather with good visibility surely provokes higher speed while rainfall, wind and visibility limitations will force drivers to reduce speed, drive with more concentration, and be more cautious. In the light of emerging new possibilities of acquiring data on vehicle speed, especially travel speed indicating the speed of trip between designated speed measurement points using modern measurement technology new researches are possible. Increasingly in the ITS systems being implemented mainly in urban areas, ANPR (Automatic Number Plate Recognition) cameras are one of the ITS element. These cameras make it possible to determine the real time of appearance of the vehicle in the register area of the camera, thus determining both the matrix of trips between each two observation points (ANPR cameras), but also the vehicle's ride time between successive cameras, and thus the speed of trip. In conjunction with data on weather conditions registered by several dedicated weather stations, they allow to significantly increase the research sample in terms of vehicle speed, and thus to obtain a statistically more confident inference. Thus, it gives a chance for further analysis regarding the impact of atmospheric conditions on road traffic conditions, including on travel speed and capacity of transport infrastructure. The article will present the results of empirical analyses to determine the impact of weather conditions (including temperature, ice thickness, air pressure and precipitation) on the vehicle trip speed.

1. Introduction

Studies of the impact of various external factors on the behaviour of vehicle drivers play a powerful role in both planning transport investments and in the field of typically engineering activities. This applies, among others technical facilities of road infrastructure, protecting road users in case of a mistake committed by at least one of them. Undoubtedly weather conditions are one of the factors that affects the above behaviour of road infrastructure users. Since changes in weather conditions affect the behaviour of people as evidenced by authors of the work [1], it is hardly surprising that they should play an important role in transport. Hence, the impact of weather conditions on transport has been analysed for many years. Among others the authors of the paper [2] showed in their work based on 10-year Dutch studies the influence of weather conditions on travels related to their various trips' destinations. These studies prove that weather conditions affect the transport demands of residents, and in particular the issues of mode choice decision to do a trip (e.g. by private car or by bike, by public transport or walking). More detailed research on the impact of the weather was dealt with,

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among others, in [3], where in their publication based on research in the area of Istanbul, the authors indicate that rain affects the speed reduction from 8% to 12%, and wet surface by 6-7%. The Americans in their publication also investigated the impact of atmospheric conditions on speed and capacity in urban traffic [4]. They indicated, the impact of rainfall on vehicle speed reduction from 4 to 12% and road capacity up to 27%. Similarly in [5], the authors indicated a 4.0-6.0% speed reduction in the case of heavy rainfall, as well as snow at 5.5-7.6% in the case of light snowfall and 7.4-11.4% for strong snowfall. As shown above, the results are similar but point to differences. It can be argued that the impact of weather conditions on the behaviour of drivers, i.e. the style of driving a vehicle results from various premises, including, among others. from the frequency of rainfall, as well as the get to feel the given weather conditions by road users. It seems logical that drivers in areas where frequent snowfalls are commonplace much easier deal with heavy snowfall than drivers, for whom snow is a rare atmospheric phenomenon. This can be called the effect of habituation of drivers to given weather conditions. Therefore, there is a need for further work on the impact of weather conditions on the speed the drivers drive their vehicles, and thus on road capacity. It should be emphasized that almost all methods of capacity calculation assume good weather conditions, which are rare in many areas of the world [4].

The purpose of this paper is to present preliminary results of tests such weather parameters as temperature, atmospheric pressure, precipitation and ice thickness affecting the average trip speed of vehicles in the urban area with a negligible impact of traffic on these speeds. The analyses were based on measurements carried out in a medium-sized city in Central Europe, in Poland, in a moderate climatic zone, prepared during over a 100-days observation period from the beginning of December to the middle of March, that is in the winter time when weather conditions are very variable, with temperature range from minus 10.7ºC to plus 15.6 ºC, atmospheric pressure from 976 to 1046 hPa, rainfalls and snow, but also excellent ones. These observation were done during the night period, in darkness, from 0.00 to 5.00 am in various weather conditions, when no congestions situation were recorded. Automatic data on the vehicle speed and type were registered by the local ITS system equipped with 66 ANPR cameras. The use of such cameras in traffic analysis together with a different methodology of analysis has been presented, among others at work [6].

The remainder of the paper is organised as follows. The description of the study area, and traffic and weather data (study data) are presented in the second section. In the third section the methodology of the study are provided. The result of the analysis are presented and discussed in the fourth section, while conclusions are drawn in Section 4.

2. Study area and data

The study area is located in the Centre Europe, in the city of 350 000 inhabitants, and the network of over 850 km. The traffic and speed data are provided by the local ITS system, where Automatic Number Plate Recognition (ANPR) cameras enabled to collect sufficient data from the main road network detail (see Figure 1). The study period spans from December the 5th, 2018 to March 13th , 2019, that is the winter time, since 0 am till 5 am, that's in night time when streetlights are on, while traffic congestion were not observed. This time spans was selected, to eliminate impact of traffic on test results. The average trip speed distribution during a test period is presented in Figure 2. As one can observe the top speed of vehicles if observed between 0^{00} and 5^{00} am, while the high level of service on the road network is observed and the speed limit is defined as 60 km/h. This speed limit this time is higher than the typical one during the daylight over 10 km/h what is the consequence of Polish legislation. That's why these hour slots were selected for the further analyses. Moreover the impact of junction was included in the analysis. As it is presented in Figure 3, impact of section length for average trip speed of cars and truck is significant. The average trip speed of vehicles in links with length bellow 0.5 km is much lower than the same speed calculated for rest links. It is because of junction impact zone. Typically vehicle drivers approaching a junction need to reduce vehicle speed

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because of road signs, road signals, and right of way. Due to this only links longer than 0.5 km were taken into analyses. In the most cases selected links represent double carriage ways with high capacity and speed limit 60 km/h at night time, and one of them is marked as the speed limit of 70 km/h. All of them were lit by streetlights.

To estimate the average trip speed for each individual, link each individual trip time for the given link were calculated. Two ANPR cameras located on the start and the end node of the tested link were used. In each case camera is located at a junction outlet. One single vehicle plate together recorded by the entrance camera was coded and stored in the database with the time-stamp [7]. The time of the trip for given link was calculated by matching this record with all records of vehicles' plates and time-stamps recorded by the exit camera. An average trip speed of vehicles in a link ($LV_{i,t}$) is then calculated for every link i and 60-min interval t as follow:

$$VT_{i,t} = \frac{1}{N_{i,t}} \sum_{k=1}^{N_{i,t}} \frac{L_i}{3600 t_k} \tag{1}$$

where $VT_{i,t}$ = average trip speed of vehicles (km/h) of the link i during the time interval t; Li = one link length (km) – the distance from the start to the end node; t_k - individual tip time (s) of vehicle k along the link i during the time interval t; $N_{i,t}$ = number of vehicles matched by the system on the link i during the examined time interval t.

There are lots of combinations of ANPR cameras pairs in the system, but only 42 were selected for examinations. It was because lots of them consist multiple duplicate links.

Hourly weather data were collected by seventeen weather stations allocated in the study area (see Figure 1). Their locations were selected to cover the whole study area in the best way. For each individual link the closest weather station was selected. As the data were aggregated into one hour

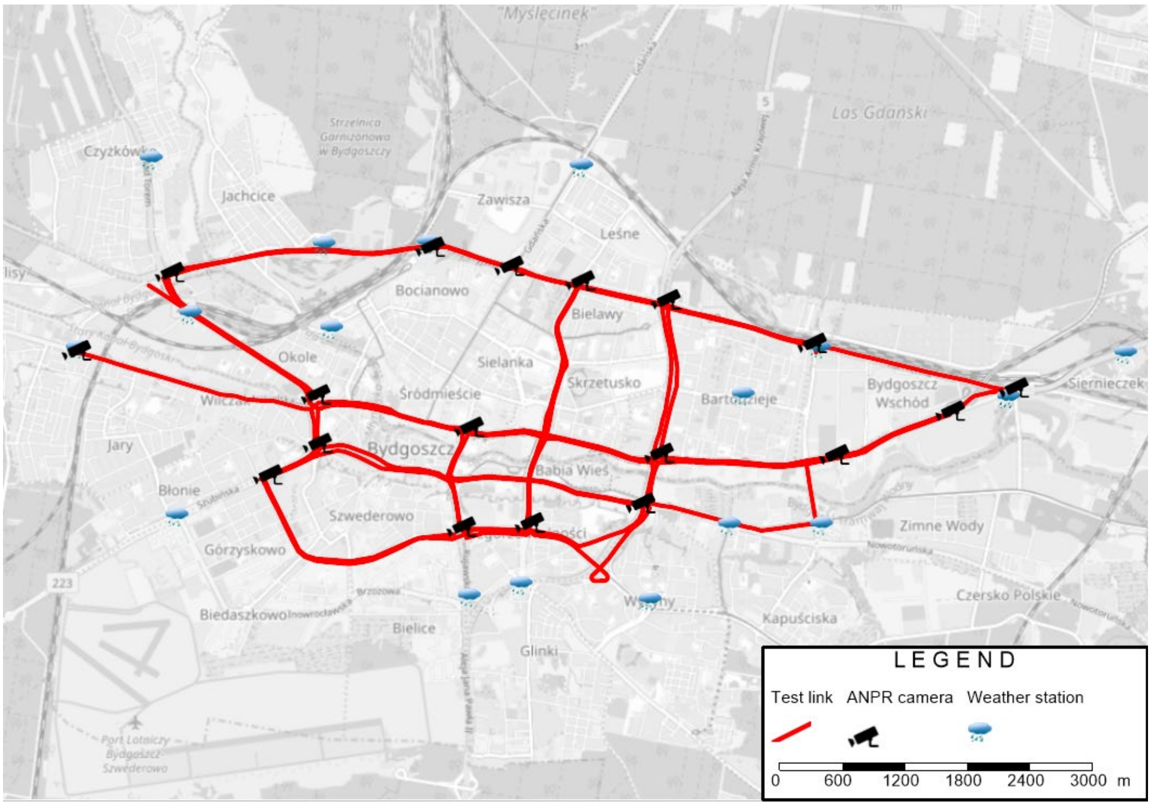

Figure 1. Location of ANPR cameras, weather stations and test links used for the main analysis

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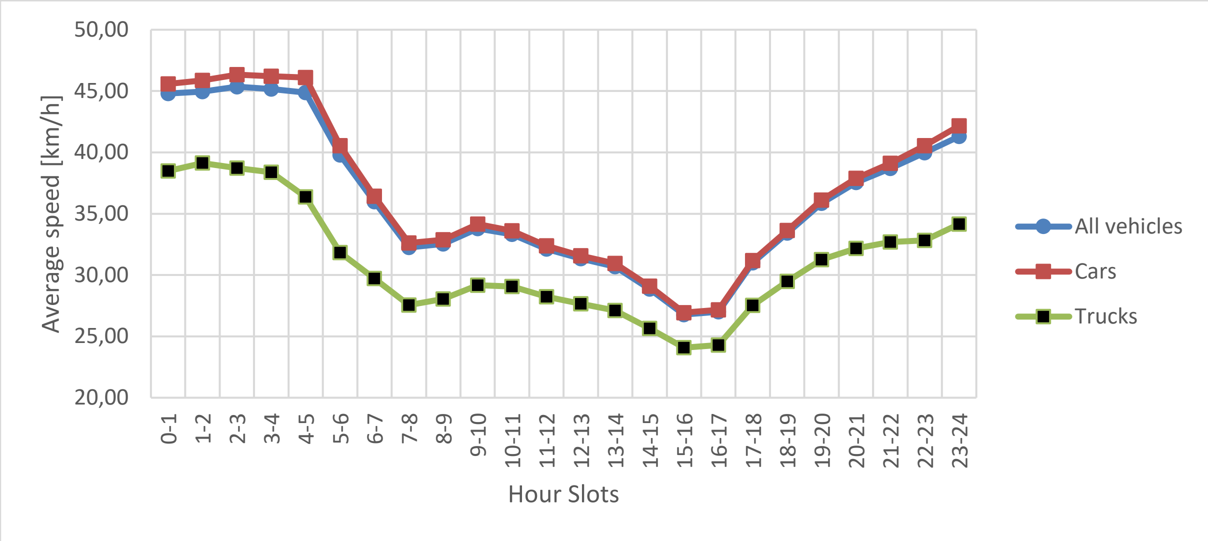

Figure 2. Average trip speed distribution during a test period

time slots, the average values were calculated for each hour. The data set includes four variables: precipitation (mm), atmospheric pressure (hPa), air temperature (°C) and ice thickness (mm). Is should be noticed the study area is rather homogeneous nature and weather parameters measured by each weather station do not differ significantly. Finally, the hourly intervals of the weather data set and ANPR database records were matched what enabled the further analysis. It should be underlined the local Road and Public Transport Administrator (RPTA) is responsible for the ITS system calibration, verification and maintenance. That's why less than 10 hours of the study period had to be eliminated due to the system maintenance and calibration procedure made by the specialist employed by the RPTA.

In order to determine the impact of the weather conditions on average trip speed of vehicles, the *VTs* under base different conditions are compared to different intensities of rain, ice thickness, atmospheric pressure and air temperatures. Moreover the base conditions were defined as 'dry road surface' resulting from good weather conditions, no rain or snow, and the temperature is higher than 9ºC [5]. The *VTs* under the base conditions against the corresponding speed in different intensities of precipitation, ice thickness and low temperatures represents impact of weather conditions into vehicle speed.

3. Results and discussion

Tables 1–4 and figures 4-8 present average trip speeds of vehicles *VT* for the examined categories of temperature, air pressure, precipitation, and ice thickness. The average number of vehicles per link per hour in the given category indicates number of vehicles matched on this link in the beginning node and the end node in the given weather condition in one-hour slot time. In most cases the average traffic volume is between 100-200 veh./h. It means observed traffic volume is not high and on the same level so it is justified to compare the test results. In the following sections obtain results for each tested weather parameter is discussed.

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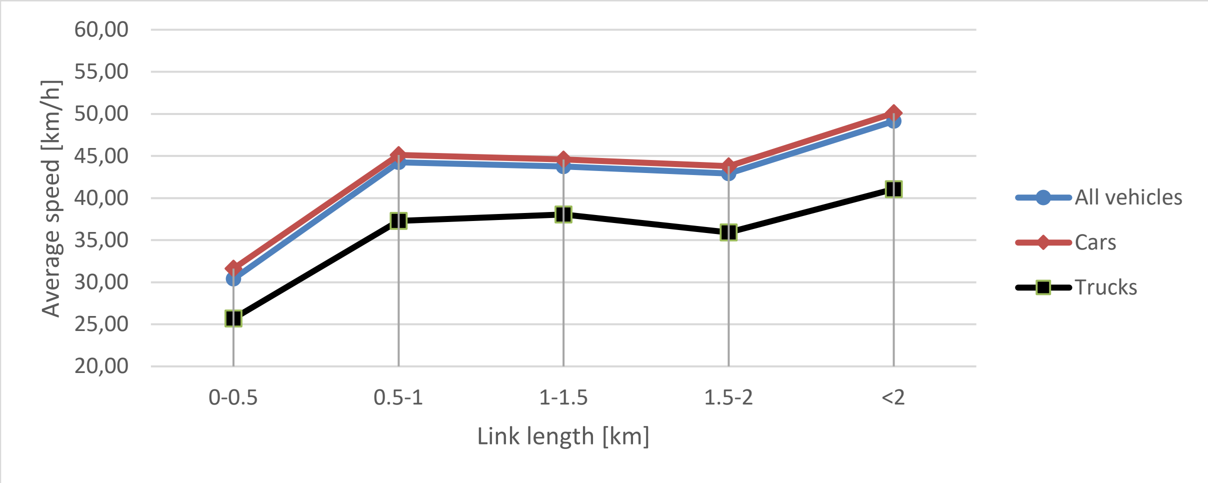

Figure 3. Average trip speed of vehicles on link in relation to links length

Table 1. VT for different air temperatures.

Air temperature [ºC]	All vehicles	*N per link* [a]	Cars	*N per link* [a]	Trucks	*N per link* [a]
below -9	45.50	104	46.55	89	37.77	15
-9 to -7	44.65	140	45.46	125	37.15	15
-7 to -5	44.16	161	44.81	146	36.86	15
-5 to -3	45.09	102	46.12	88	37.57	14
-3 to -1	44.69	125	45.58	109	37.21	16
-1 to 1	45.17	115	46.02	100	38.46	15
1 to 3	45.25	121	46.08	107	38.17	14
3 to 5	45.41	118	46.18	105	38.75	13
5 to 7	45.28	134	46.14	118	38.26	16
7 to 9	45.18	145	46.20	127	37.88	18
over 9	46.19	124	46.81	111	38.62	13

[a] Note: *N per link* denote the average number of vehicles per link per hour

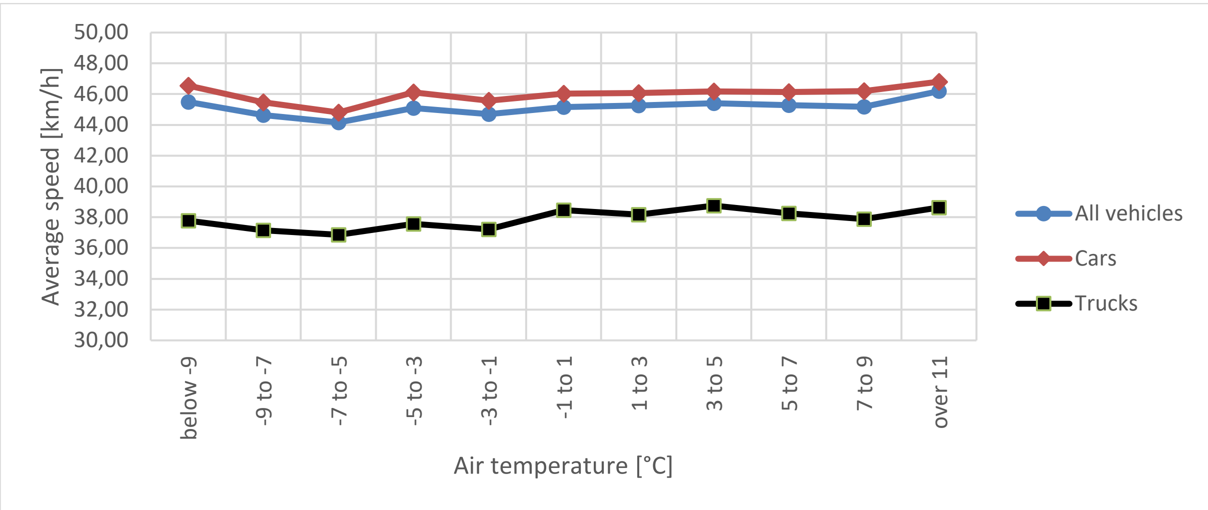

Figure 4. Average trip speed of vehicles on links for different air temperatures.

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Table 2. VT for different precipitation

Precipitation [mm]	All vehicles	*N per link* [a]	Cars	*N per link* [a]	Trucks	*N per link* [a]
No precipitation	45.41	184	46.28	162	38.40	22
0.0-0.2	45.35	190	46.25	165	38.35	25
0.2-0.6	44.05	185	44.90	163	37.11	22
0.6-1.0	45.21	61	46.03	48	37.85	13
1.0-1.4	45.56	116	46.34	102	38.70	14
1.4-1.6	45.31	149	46.07	126	38.25	23
1.6-1.8	45.05	188	45.82	170	38.15	18
over 1.8	44.79	196	45.58	175	38.05	21

[a] Note: *N per link* denote the average number of vehicles per link per hour

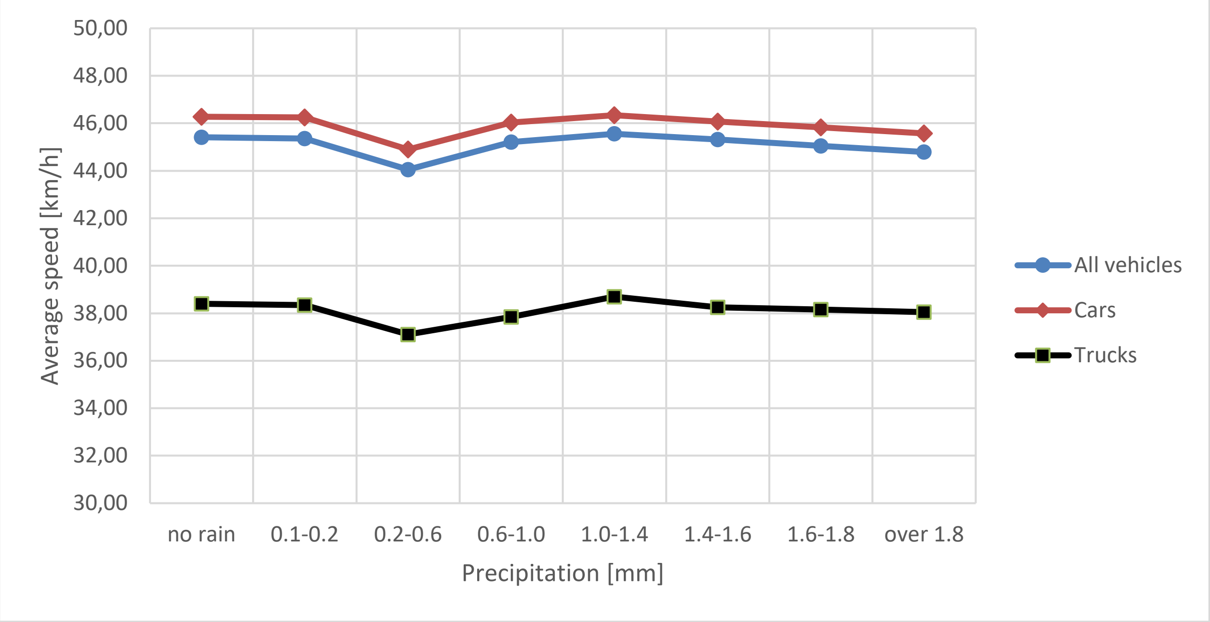

Figure 5. Average trip speed of vehicles on links for different precipitation.

Table 3. VT for different atmospheric pressure

Precipitation [mm]	All vehicles	*N per link* [a]	Cars	*N per link* [a]	Trucks	*N per link* [a]
below 984	44.56	218	45.52	191	37.67	27
984-991	45.20	185	46.19	163	37.30	22
991-998	45.11	203	45.99	178	37.69	25
998-1005	44.66	201	45.53	177	37.53	24
1005-1012	45.19	169	46.09	148	38.01	21
1012-1019	44.96	191	45.82	168	37.85	23
1019-1026	45.02	195	45.96	171	37.53	25
1026-1033	44.94	177	45.87	153	37.91	23
over 1033	44.80	175	45.30	163	39.12	12

[a] Note: *N per link* denote the average number of vehicles per link per hour

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Table 4. VT for different ice thickness

Precipitation [mm]	All vehicles	*N per link* [a]	Cars	*N per link* [a]	Trucks	*N per link* [a]
no ice	45.12	182	46.01	162	37.91	20
0-1	44.54	196	45.46	172	37.30	24
1-4	42.52	309	43.10	285	34.43	24
4-7	42.84	270	43.54	241	36.97	29
7-10	43.68	220	44.51	197	35.96	22
over 10	43.01	215	43.94	192	34.76	23

[a] Note: *N per link* denote the average number of vehicles per link per hour

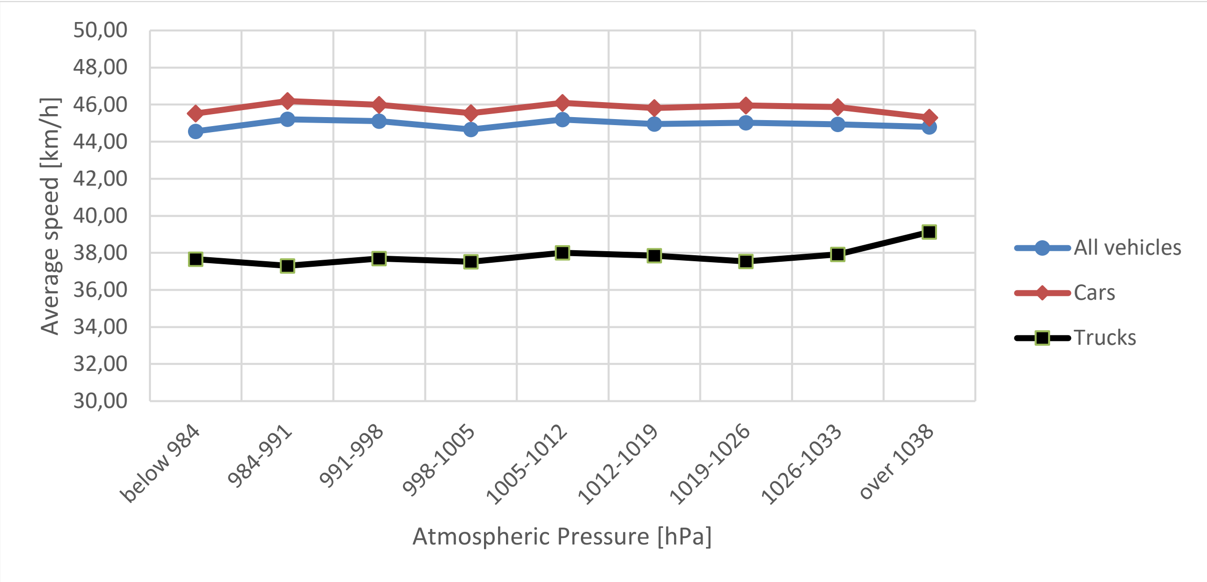

Figure 6. Average trip speed of vehicles on links for different atmospheric pressure.

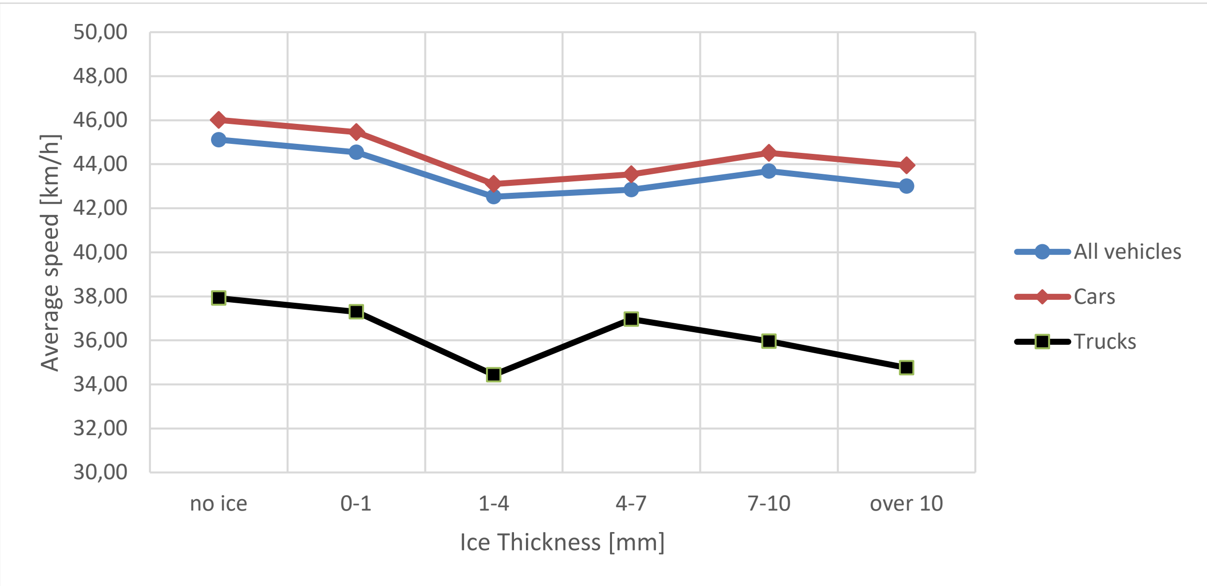

Figure 7. Average trip speed of vehicles on links for different ice thickness.

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3.1. Air temperatures
The values presented in Table 1 and I Figure 4 indicates that temperature has an impact on trip speed. The lowest speed values are observed between -7 ºC to -1ºC, while road surface can be slippery. It probably causes drivers are more careful and they do not drive to fast keeping in mind it is easy to slip, especially during braking. What's more, such a road condition probability causes drivers to start braking the vehicle quicker and gently by approaching an intersection and start to drive with greater respect, which takes more time and causes a lower average trip speed. The average trip speed of vehicles is almost 5% lower comparing to the average trip speed in the base conditions, when the air temperature is over +9ºC. What should be noticed the average trip speed of vehicles goes up when the air temperature is below -7 ºC. Nowadays it is quite normal in the Central Europe low air temperature (below -7 ºC) is quite rare phenomena and typically there is no snow that time. That is why drivers can drive faster than in case of air temperature between -7 to -3ºC. In range between 1 to 9 ºC the average trip speed of vehicles is almost the same it is averagely approx. 2.35% lower than the base one. And the difference between the average trip speed of cars and trucks is the highest in very low air temperatures below 19% lower in case of truck while it is over 17% lower in positive values of air temperature. According to studies [4] temperature has nearly a negligible impact on vehicle speed, however cold temperatures yield increases in travel times and make average trip speed of vehicles lower. More research should be done in the future in this field taking into account other aspects like the tested links length.

3.2. Precipitation
It was reported by Wang L. [8], in an average speed decline over 6 km/h during heavy rain and heavy rain has the most significant effects on vehicle speed [9]. The analyses presented in this paper prove that results. The first moments of rain, when rain measured by weather stations was in range 0.2-0.6 mm per hour caused decline of the average trip speed of vehicles over 4% while after that, in the range over 0.6 mm per hours, caused only 2.0% decline of the average trip speed (see Table 2 and Figure 1). What is more surprisal the average trip speed of trucks is the same during precipitation in the range 1.0-1.4 and with no rain condition. It may be explained drivers become familiar with wet road survey and they drive their typical style like in case of no precipitation. After this point one can observer lower the average trip speed of vehicles due to increase of precipitation intensity. More results are necessary to explain this phenomena especially in range of heavy rain with more than 6 mm/h what should be expected during spring and summer time, when showers and storms may be expected.

3.3. Atmospheric Pressure
The impact of atmospheric pressure into average vehicle speed was reported by Sodre J. R. in [10], but this issue is not often mentioned in the state-of -art. It should be mentioned that it is well established that high pressure is generally associated with nice weather, clear sky, dry and stable weather, while low pressure is generally associated with cloudy, rainy, or snowy weather. Moreover, colder months of the year experiences more low pressure situations, and the test results come from winter time. As it comes from the other analyses presented in this paper rainy weather generally cause lower average vehicle speed. In this work the results are presented in the Table 3 and Figure 5. On the base of presented results one can say the atmospheric pressure doesn't not play an important role. The changes in average trip speed of vehicles in particular ranges are not significant.

3.4. Ice Thickness
Ice thickness is the last parameter tested in this work. The results presented in this paper prove the thickness of ice affects the average vehicle speed. As shown in the Table 4 and Figure 6 the average trip speed of vehicles decreases by a percentage of percent with the thickness of the ice, while road surface condition makes trips dangerous to road users. As it is presented the first part of ice on road surface till 4 mm causes the average trip speed is reduced by 7% in case of cars and over 10% for trucks. Small increase in the average trip speed of vehicles is observed after that point, which may

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result from drivers getting familiar with icy road surface and allowing to drive with slightly higher speed.

4. Conclusions

This paper presents the first results of traffic observation during a winter time. It should be underline, the changes in climate in this region of Europe are undisputed, and they have already caused, weather conditions are not as difficult as they were observed in the 80's and 90's of the previous century. Snowfalls are rather rarity, while light snowfall and rains are observed. One can say the autumn weather is unimaginably the same. Further observation of road traffic in the spring and summer seasons will allow to draw further conclusions on the impact of weather into traffic speed in urban area in this part of Europe.

The following conclusions were reached by the results of the study:

1. Night time defined as the period between 0^{00} to 5^{00} am is characterised by the adequately high average trip speed of vehicles on road network in the study area, 33% higher than the average trip speed between other hours.

2. During the whole day the average trip speed of truck is at about 15% lower than the same trip speed of cars, while in the night time it is over 17% lower.

3. The relationships among average trip speed of vehicles and weather parameters like air temperature, precipitation, atmospheric pressure and ice-thickness, as observed from the analysis of empirical data at the study area are in general comparable with the ones documented in the literature.

4. First moments of rain reduced the average trip speed of vehicles by 4%, however after that drivers become familiar with wet road surface and rainy conditions and the average trip speed is reduced only by 2%.

5. The impact of atmospheric pressure on average trips speed of vehicles is minimal and it seems to be more correlated to other phenomena associated with atmospheric pressure, like e.g. rainfalls.

6. Ice surface conditions resulted in a reduction of average trip speed by 7% in case of cars and 10% for trucks.

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